The use of a Pharma Compounds augmented reality educational tool in sixth form and undergraduate students: a mixed methods evaluation

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Abstract

Augmented reality (AR) generates immersive, engaging environments that has been shown to improve learners' motivation, knowledge and spatial awareness in some science-based subjects. Therefore, this study aimed to design, then evaluate the effectiveness and normalisation of an AR educational tool (Pharma Compounds) in students learning about pharmacologically active biological compounds (sixth form students and second year pharmacy students).

Following ethical approval, a questionnaire survey among students and tutors informed the design of the Pharma Compounds AR educational tool. The AR tool was then evaluated using a mixed-methods study design, utilising pre- and post-knowledge-based quizzes and questionnaires, followed by semi-structured interviews with students and tutors (theoretically informed by NPT). Quantitative data was analysed using descriptive and inferential statistics. Qualitative data was analysed using content analysis and framework analysis.

A marginal but non-statistically significant increase was found in the mean pre- and post-intervention knowledge-based-quiz scores (7 vs 7.5, 6 vs 7 and 10.69 vs 11, pre- vs post-quiz respectively). Participants reported perceived improvements in their knowledge after the use of the Pharma Compounds AR tool. There was a statistically significant increase in participants' self-reported intrinsic motivation towards learning after using the AR tool compared to before its use. Perceived improvements were also reported in their intrinsic motivation towards learning and visualisation ability. NPT-informed qualitative data analysis

suggested that the AR tool could be normalised in educational environments if a broader but tailored range of topics are included.

These findings suggest that the AR tool did not improve the objective knowledge of learners although they reported perceived improvements in their understanding. The intrinsic motivation towards learning of users in science-based subjects improved with the use of the AR tool, as it offered alternative perspectives of 3D concepts and phenomena. With further improvements in content and functionality the Pharma Compounds AR tool may readily be normalised into educational environments. Further studies should evaluate similar tools within larger populations as this study was heavily impacted by the COVID-19 pandemic.

Acknowledgements

There are several people whom I must thank, for without their support, none of this would have been possible. Firstly, I would like to show my appreciation for my supervisory team - Professor Steven Chapman, Dr Simon White and Dr Jessica Thompson. Thank you for your guidance, support, and continued reassurance throughout this process. I am incredibly humbled and grateful for all your efforts.

To my fellow PhD students, thank you for your advice and willingness to support me at every stage of my PhD research journey. Your tips and tricks proved extremely valuable over the years. I would also like to thank all the participants, tutors, and schools involved in this research programme. Your involvement and responses shaped the development and evaluation of the Pharma Compounds tool; without your participation, this indeed would not have been possible.

Finally, my family – mum, dad, Jerome and Jordan. Words cannot describe what you all mean to me; thank you! It has been a long journey that, at some points, felt impossible. Yet you were always by my side, supporting me. Thank you for your unconditional love, unwavering support, encouragement and patience. I would not be the person I am today without every single one of you.

Table of Contents

List of Figures

List of Tables

Abbreviations

2D – Two Dimensional

3D – Three Dimensional

ANOVA – Analysis of Variance

AR – Augmented Reality

APP – Application

CBA – Competency Based Assessment

DNA – Deoxyribose Nucleic Acid

GDPR – General Data Protection Regulations

GPhC – General Pharmaceutical Council

GPS – Global Positioning System

HE – Higher Education

ICT – Information and Computer Technology

IMI – Intrinsic Motivation Inventory

MCQ – Multiple Choice Questions

MPharm – Master of Pharmacy

NMR – Nuclear Magnetic Resonance

NPT – Normalisation Process Theory

OSCE – Objective Structured Clinical Examination

PICOS – Participants, Intervention, Comparators, Outcomes and Study Design

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analysis

STEM – Science, Technology, Engineering, and Mathematics

UK – United Kingdom

VR – Virtual Reality

1 Introduction

1.1 Foreword

This thesis presents a mixed methods study that evaluated the usefulness of an augmented reality (AR) system as an educational tool for both sixth form (Biology and Chemistry) and Undergraduate (Pharmacy) students when incorporated into their current learning methods.

Before discussing the role educational tools play and how they are incorporated into education, consideration is first given to how teaching and learning occur at different stages of education. As such, this chapter begins with section 1.2, detailing a brief overview of post-16 education (Key Stage 5) in the United Kingdom before moving on to undergraduate pharmacy education in section 1.3. Aspects of pedagogy, focussing on relevant learning theories are briefly discussed in section 1.4 (learning theories in practice in section 1.4.1, Kolb's Experiential Learning Cycle in section 1.4.2, Bloom's Taxonomy in section 1.4.3 and Active Learning in section 1.4.4). This chapter then turns to look at the use of educational technologies in science-based subjects in section 1.5. Next, in section 1.6, the history of augmented reality is explored before looking at the different types of augmented reality systems currently available (section 1.7). Section 1.8 then gives a brief introduction and overview of the structure of this thesis.

1.2 Post-16 Education

Post-16 education within the United Kingdom (UK) is broadly undertaken in three types of institution: sixth form schools, further education sector colleges and higher education (HE)

institutions. These categorisations, however, rather oversimplify the complicated dynamic of educational provision and relationships between establishments (Bocock and Scott, 1994; Ertmer and Newby, 2008).

In England, 16-19-year-old individuals are expected to remain in some form of education or training in accordance with the Education and Skills Act (2008). Consequently, sixth form schools, sixth form colleges or further education (FE) colleges are popular destinations for 16-year-old students upon completing their GCSE examinations. In many cases, sixth form schools and colleges enable students to achieve level 3 (figure 1.1) qualifications over two years - FE colleges also provide such opportunities to students and individuals who may be over 18. The Level 3 qualification courses on offer at such institutions include the International Baccalaureate Diploma (IB), BTECs and level 3 National Vocational Qualifications (NVQ) and diplomas, the new T-level, and finally, AS and A levels being the most popular option (Department for Education, 2021, 2016).

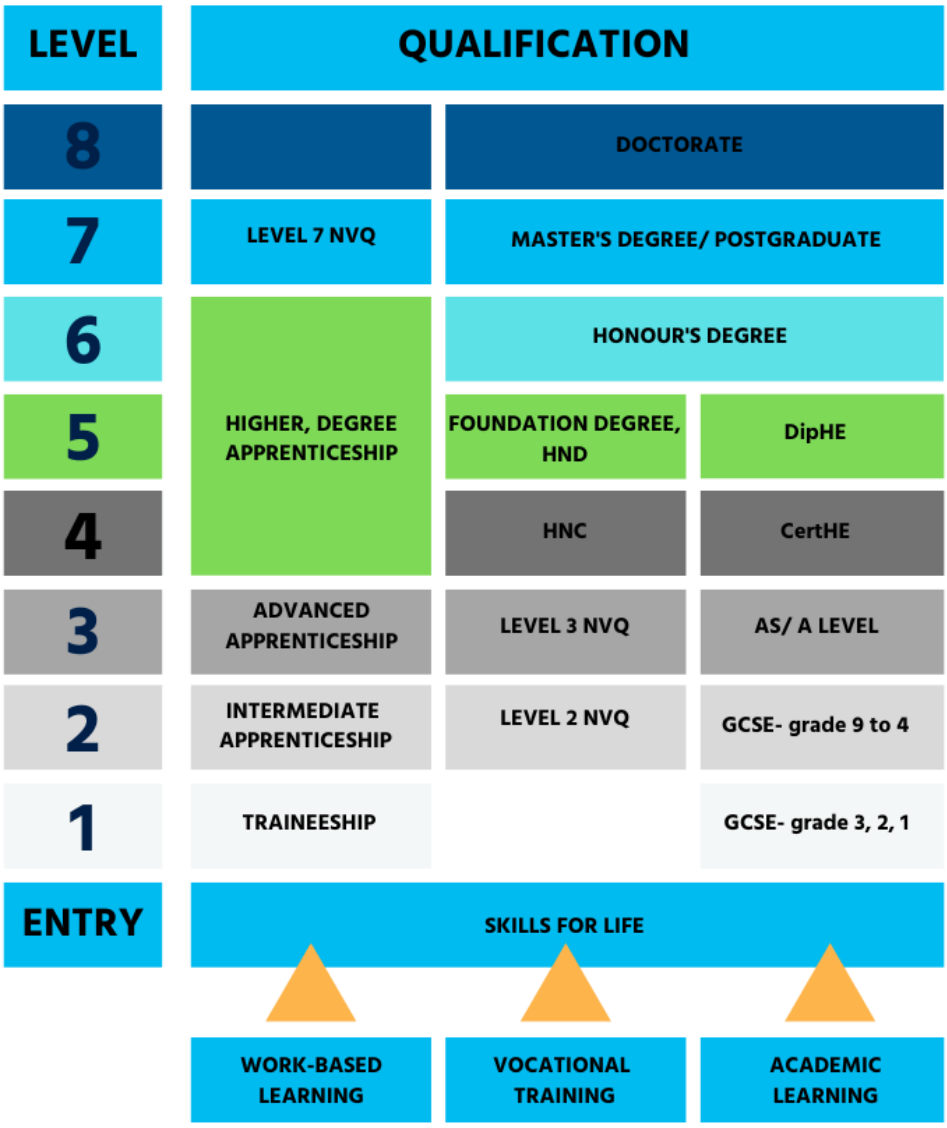


Figure 1.1 Qualification framework taken from Ukstudyonlie (ukstudyonline.com, 2023)

Following reforms made by the UK government, A-Level qualifications changed from a modular structure to a linear format (Long, 2017). The older modular arrangement broke the learning material into self-contained units that were well-defined with clear boundaries between topics. In most cases, the different subject areas had very few links to each other. In many subjects offered to AS-level and A-level students, topics and units focused on only a limited range of skills and concepts. Ultimately this arrangement restricted tutors in what order they could deliver teaching material and how much time they had to spend on each unit regardless of their students' understanding. The restructured linear model offers more

freedom to tutors and instructors. Content is viewed as a whole and taught in a more holistic style, enabling the links between key concepts and skills that underpin the entirety of each course to be purposefully emphasised (Cambridge International Examinations, 2013).

As mentioned, the newer linear syllabus gives instructors greater freedom in delivering their teaching sessions. Within the two-year A-level course, tutors can choose the order in which topics are delivered and set the pace of study to suit the individual needs of their learners. Students who study under a linear syllabus are encouraged to refer back to and build upon knowledge acquired from earlier stages of the course. As a result, they may be more prepared for examinations with a solid holistic view of the subject material. Conversely, the modular syllabus can make it more challenging to develop a lucid picture of the entire subject resulting in learners viewing the course as a series of detached fragments (Cambridge International Examinations, 2013). Concerning the linear syllabus, The Cambridge International Examinations (CIE) board (2013) reported that tutors identified a change towards the latter end of the second year of A-level courses. They found that many learners began to see the subjects holistically – students developed a much deeper appreciation of the various concepts and how they linked together. The CIE board reported that the learner's academic performance improved drastically due to remembering facts that fit neatly into the overall picture of the subject and its topics.

Reform in England's educational system extended beyond the format of individual qualifications and included the types of publicly funded qualifications available to students. In a 2021 policy statement that reviewed post-16 qualifications at level 3 in England, the

Department for Education (2021) stated that every qualification offered to learners must be of high quality with a system in place to help students make better course enrolment choices. These two elements are thought to help students possess graduate attributes that may lead to more comprehensive options for progression. The policy shed light on reforms implemented to improve qualifications and access to education, including introducing T-levels at level 3 - The first three launched in September 2020. T-levels are comprehensive, challenging programmes focusing on the best industry-relevant technical and practical-based learning courses. On the other hand, A-levels concentrate on high-level academic study (one T-level is equivalent to three A-levels) (Department for Education, 2021). A-levels, however, are still due to be the central component in the progression of the academic pathway to university. The review also detailed the removal of public funding for technical qualifications that overlapped with employer-led T-levels to help simplify the market, for example, BTEC and OCR Cambridge Technical qualifications (Department for Education, 2021).

1.3 Undergraduate Pharmacy Education

The recognised qualification that permits registration to the General Pharmaceutical Council (GPhC) as a pharmacist is the four-year Master of Pharmacy (MPharm) programme followed by a one-year compulsory work programme ("foundation year") before a licensing examination can be taken. Once passed, a registration application can be made. Some universities within the UK have adopted a five-year programme where blocks of intercalated foundation year training occur, totalling the stipulated 52-week duration (GPhC, 2011). Universities are being encouraged to adopt the five-year programme due to the broadening role of a pharmacist and the potential benefits related to the combined effect of theory and

practice on learning (GPhC, 2015, 2011; Illing *et al.*, 2008). Like the linear A-level restructure, the five-year MPharm program (compared to the four-year course) may afford tutors further freedom to teach students (GPhC, 2011). Key concepts encountered in practice can be revisited and further explored in controlled teaching sessions with input and perspectives from colleagues and student peers.

The standards of education set out by the GPhC require pharmacy schools to have a curriculum that integrates practical experience in various environments (real life and simulated) alongside conventional academic education (GPhC, 2021). This does not explicitly mean that initial education and training must be delivered one after the other in a 5-year programme of instruction. Still, elements of education and training must be constructed in a fluid, coherent way so that the foundation year of training is intercalated with the four years of the MPharm degree (five years in total) (GPhC, 2021, 2011).

The degree must be progressive, addressing concepts and phenomena in an increasingly more complex fashion as the student progresses through each level of the course. Such a curriculum would form a metaphorical spiral, where subjects and themes would be revisited throughout the course. However, for this style to succeed, the material must not simply be reviewed; it must also be deepened with each successive encounter, building upon the last (Gibbs, 2014; Harden and Stamper, 1999; Murray, 2016).

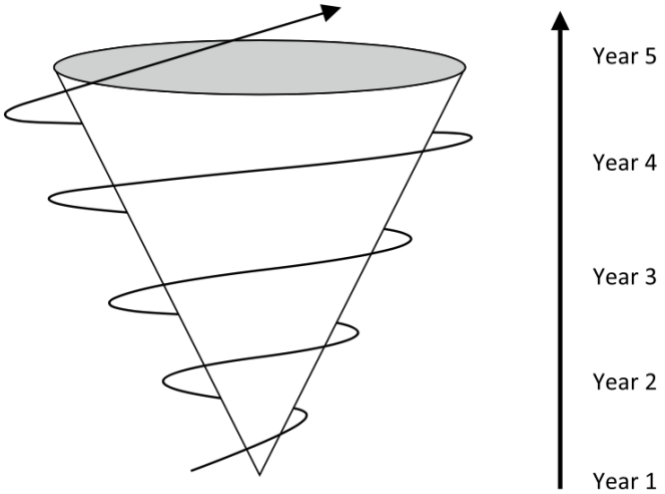


Figure 1.2 Spiral Curricula taken from Standards for the Initial Education and Training of Pharmacists 2011 (Harden and Stamper, 1999)

Jerome Bruner first described this model (1960) and noted the fact that the successful teaching of highly structured subjects, such as mathematics, physical science and history, would frequently take on a metaphorical spiral; initial ideas are introduced intuitively, and once mastered, are revisited and re-construed more formally. Following this, the acquired knowledge is connected with a learner's established older knowledge and understanding to become further situated before being carried a step higher to a new broader level of rigour and comprehensiveness. This process enables an individual to masterfully connect and structure large bodies of knowledge (Coelho and Moles, 2015; Rockich-Winston, 2017). This same metaphoric spiral is effectively required by the GPhC to be present in pharmacy education. For example, students may encounter a specific core principle of chemistry surrounding a functional group. Upon revisiting, the same principles and concepts are embedded in topics that relate to the activity of a medicinal compound that includes that very same functional group. In the next spiral, students may be taught how and why that therapeutic compound or drug is used to treat specific diseases.

The GPhC stipulates standards for the initial education and training of students that must be met before graduation. At each revolution of the spiral curriculum, competence in these standards is typically assessed using Miller's Triangle (GPhC, 2021; Miller, 1990).

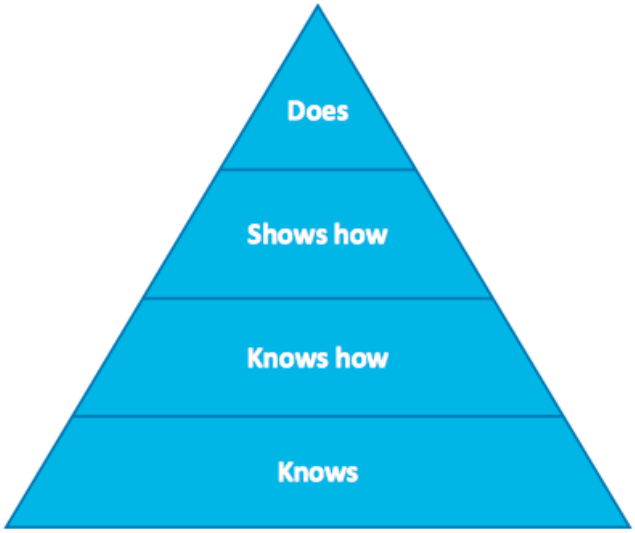


Figure 1.3 Miller's Triangle taken from Standards for the Initial Education and Training of Pharmacists 2021

Although this model was initially developed to assess clinical skills, it can also be applied in science education (Cruess *et al.*, 2016). Miller's Triangle has been a template for developing various teaching and learning programmes and has provided a foundation for different systems that evaluate an individual's professional competence (Cruess *et al.*, 2016; Hawkins *et al.*, 2009; Hodges *et al.*, 2011). During undergraduate years, students can find themselves at different levels of Miller's Triangle due to different life experiences (i.e., some students may have had more professional experience than others by working in pharmacies through a hospital, community, or industry placement). Each year of the MPharm degree covers content, skills and concepts that build in complexity with students' acquired knowledge, all of which require assessment. As a result, it is necessary to utilise a variety of assessment formats to assess the range of learning objectives (Witheridge *et al.*, 2019). Students who

find themselves at the ‘Knows’ stage of Miller’s Triangle typically possess the knowledge of what is required to complete the necessary task. They are often assessed with knowledge recall assessments such as multiple-choice questions (MCQs) and short answer questions. At the ‘Knows how’ stage, students are characterised as knowing how to apply their acquired knowledge and skills and can be assessed with clinical problem-solving exercises and extended MCQs. The following stage, ‘Shows how’, indicates that students can perform or demonstrate the acquired skill or knowledge, for example through simulations of real-world experiences or theoretical scenarios. In most cases, standardised patient exercises, simulations and clinical exams are used to assess learner competency. For students to attain the final level of Miller’s Triangle, the ‘Does’ stage, they must be able to consistently and independently demonstrate their knowledge or skill in complex situations every day and can normally be assessed through observations (GPhC, 2013, 2011).

In educational disciplines, such as pharmacy, where progression in competency is critical to professional development, Miller’s Triangle may provide a basic checklist for learners to assess their level of competence as they progress through their education. Nevertheless, Miller’s Triangle is not without its limitations. He acknowledged that the model was based on conjecture, like most frameworks. The Triangle is based on the belief that assessments in real-world scenarios would give a better account of a learner's performance than simulated assessment scenarios (Norcini, 2003). Miller assumes that observations at the ”Does“ stage in real practice provide a truer account of a learner's ability than observations in simulated environments. The issue with this idea is that no two real-world cases are the same, especially concerning healthcare. Therefore, it may be difficult to evaluate a learner's proficiency at the top of the Triangle (Norcini, 2003; Ramani and Leinster, 2008). Another

limitation associated with Miller's Triangle is the assumption that competence at the “Does” stage predicts future good performance. In actuality, many other factors can contribute to the performance of an individual, such as availability, time, mood, the environment and the patient and therefore justifies the use of varied assessment to measure a learners competence (Carr, 2004).

1.4 Pedagogy

Educational learning theories and teaching models such as Miller’s Triangle and the Spiral Curricula are the cornerstones of all education practices as they provide a framework to explain how learners acquire knowledge, skills and attitudes to achieve desired changes in behaviour, performance and potential (Aliakbari *et al.*, 2015; Mukhalalati and Taylor, 2019; Sadker and Sadker, 1991). The term ‘pedagogy’ appears in recent literature discussing educational learning theories; however, researchers and writers from various countries, disciplines and backgrounds have struggled to construct a universally agreed definition. British educators have offered brief descriptions, the most common being ‘the science of teaching’ (Watkin and Mortimore, 1999). In fear of restricting the definition of pedagogy to science, Watkins and Mortimore (1999) coined a broader definition of pedagogy as ‘any conscious activity by one person designed to enhance learning in another’. This definition incorporates the roles of the teacher and the learner in the interaction. Watkins and Mortimore further elaborated on their definition of being inclusive of the arts but stressed the importance that it should be seen as neither a science nor an art but rather as a craft (Marland, 1993; McDonald, 1992). The UK Universities’ Research Assessment Exercise (replaced by the Research Excellence Framework in 2008) used the term pedagogy to refer to contexts, relationships, processes, experiences and outcomes of teaching and learning in

HE (RAE, 2006). Pedagogy, therefore, is a term that relates to the theory of teaching, and the implementation of that theory across all disciplines and activities associated with learning (Beetham and Sharpe, 2007).

The terms ‘learning’ and ‘education’ are often used in place of one another. Both terms relate to the transfer and acquisition of knowledge, behaviour, skills or attitudes but describes the experience from opposite perspectives. Learning relates to the learner, the individual in whom changes occur as a result of the learning process (e.g. change being behaviour, knowledge, skills, or attitudes). On the other hand, education relates to an activity designed to change an individual or group's knowledge, skill, attitude, or behaviour. The educator is the individual who facilitates the changes and is responsible for designing activities that will bring about those changes (Knowles *et al.*, 2005).

The ages of students can vary quite significantly between sixth form colleges and HE institutions such as universities. Knowles (1968) coined the term andragogy to define adult learning and differentiate it from pre-adult schooling (pedagogy). Andragogy has five underlying assumptions that describe the adult learner:

- The learner can direct their learning and has an independent self-concept.
- The learner has accumulated a reservoir of life experiences that is a rich resource for learning.
- The learners’ needs are closely related to changing social roles.
- Learning is problem-based, and the learner is interested in the immediate application of knowledge.
- The learner is motivated to learn by internal rather than external factors.

However, others have since suggested that there may be little difference in learning between children and adults (Elias, 1979; London, 1973; Miller, 1973). Educational theorists questioned andragogy's theoretical status, general utility and differences from progressive education applied to adults (Merriam, 2001; Rachal, 2002; Taylor and Kroth, 2009). The second area of criticism that continues in some capacity relates to the extent to which the assumptions link to the adult learner (Merriam, 2001). Some adult learners can depend highly on a teacher/instructor for structure. At the same time, a child can be a highly independent self-learner. The same principle can be attributed to an individual's motivation to learn. Adults can be motivated to learn through external factors, such as the need to undergo training or acquire knowledge to maintain proficiency in their job. In contrast, a child may be motivated to learn through sheer curiosity or the internal satisfaction of learning. Finally, there are criticisms relating to probably the most apparent assumption – adults have varied and more profound life experiences that can positively affect a learning situation (Merriam, 2017). Merrictm *et al.*, (1996) and Hanson (1996) suggested that certain types of life experience can form negative barriers to learning, and in some cases, children may have experiences that are qualitatively richer than an adult's (Flynn *et al.*, 2011; Kudliskis, 2022).

Knowles (1980) later acknowledged those concerns and revised his thinking on andragogy. He highlighted that andragogy is an additional model of assumption about learners that should be used alongside the pedagogical model of assumptions. Knowles also suggested there would be instances where andragogy may be referred to with children and pedagogy with adults. He moved from positioning andragogy as a duality to pedagogy and instead

represented them on a continuum, ranging from student-directed learning (andragogy) to teacher-directed learning (pedagogy). The andragogy-pedagogy continuum would mean there will inevitably be an overlap in the level of educational independence demonstrated by sixth form and undergraduate learners (Merriam, 2017). The lead researcher shared this perspective, and concerning this research, andragogy and pedagogy were considered opposite ends of the same spectrum. The term pedagogy was chosen to describe the continuum due to its popularity however the lead researcher believed there might be instances where sixth form and undergraduate learners depend heavily on an educator. Similarly, there may also be instances where both groups of learners may exhibit high levels of educational independence.

1.5 Learning Theories

In the past, researchers have disagreed with the definition and principles behind learning. As a result, this led to differences in learning theory and their subsequent categorisation. For example, Hilgard and Bower (1966) identified 11 categories of learning theory. McDonald (1964) found six, and Gage (1972) ascertained three. Although researchers have different opinions on the arrangement of learning theories into strict groups, they are typically organised into one of two main categories; behaviourist or cognitive. The two groups, however, do not accommodate every single theory (Ertmer and Newby, 2013; Knowles *et al.*, 2005).

Behaviourist theories are based on environmental events or factors where each theory views learning as a process of forming an association between a stimulus and a response (Pavlov, 1927; Skinner, 1953; Thorndike, 1914, 1913a, 1913b). While these theories may no

longer be feasible in their original descriptions, many principles have been carried forward to modern-day theoretical perspectives. Learners undergo some form of conditioning that ultimately results in a behaviour change. In academia, a behaviourist would interpret a learner's correct verbal response to a question as successful conditioning and then reinforce correct responses by providing positive feedback or assigning learners good grades (Boghossian, 2006). Miller's Triangle, as discussed in section 1.3, would be considered to have behaviourist traditions due to the placement of observable behaviour ("Does") at the summit of the triangular framework (Witheridge *et al.*, 2019). Learners progress through the lower two cognition stages towards the upper two behavioural stages in pursuing competence (Sadideen *et al.*, 2013).

Cognitivism, on the other hand, is based on the concept that the acquisition of knowledge and the internal mental structures are closer to the rationalist end of the epistemology spectrum (Chapter 4.2), meaning learning involves the mental re-organisation of experiences in order to make sense of environmental stimuli (Bower and Hilgard, 1981). This theoretical perspective likens learning to individual changes between states of knowledge described as "flashes of insight" instead of changes in the probability of the learner's responses seen in behaviourism (Ertmer and Newby, 2008). Cognitive theories, such as Bloom's Taxonomy, are based on the conceptualisation of a learner's learning process and address the issues of how information is received, organised, stored, and retrieved by the mind. Jonassen (1991a) stated that learning is not concerned with what a learner does but with what they know and how they acquire said knowledge. The learner is perceived as an active element in the learning process because knowledge is described as a

mental activity that requires internal coding and structuring by the learner (Ertmer and Newby, 2013).

Cognitive models are linked to more complex types of learning, such as reasoning, problem-solving and information processing (Schunk, 2012). Simplification and standardisation are two techniques that can be used to communicate and transfer knowledge to learners both efficiently and effectively. Combining these techniques involves removing irrelevant information (simplification) before the remaining information is analysed, decomposed and simplified into more basic building blocks (standardisation). The smaller units of information enable learners to assimilate and accommodate new information faster and with greater ease (Ertmer and Newby, 2013). Most relatable to this form of learning was the old modular learning system common in A-level science education before the restructure discussed in section 1.2. The syllabus was broken down into more easily manageable sections for educators to teach and learners to digest. However, with the implementation of the linear model, as discussed in section 1.2, the opportunity to introduce simplification and standardisation may be reduced.

The main similarity between behaviourist and cognitive learning theories is the emphasis both have on the role environmental factors play in the learning process. However, the 'active' element of learning is viewed differently. Cognitive models emphasise the mental activities of the learner that lead up to the responses – planning, goal-setting and organisation strategies (Ormrod, 2012; Shuell, 1986), whereas behaviourist theories emphasise the nature of the stimuli, that being something the learner wants (reward) or fears (punishment) to illicit changes in knowledge. It is said that within cognitive theories,

environmental cues alone are insufficient to be responsible for all learning in instructional situations.

Constructivism, a cognitivism branch, equates learning with creating meaning from experiences (Bednar *et al.*, 1991). Both behaviourism and cognitivism, however, are objectivistic in that the world is external to the learner. Within constructivist modalities the learner's mind filters input from the real world to produce its reality (Jonassen, 1991b). Constructivist learning theories, such as Kolb's Experiential Learning Cycle (ELC), state that personal interpretations of the world are built rather than knowledge transferred from the world to their memories – meaning is created rather than acquired. This idea stems from the fact that a variety of possible things can be learned from a single experience which cannot be predetermined as the intended learning objective. Therefore each learner's knowledge is constantly subject to change due to their individual experiences. Bednar *et al.*, (1991) noted that to understand what learning has taken place, one would need to examine the experiences the learner has gone through.

Constructivists consider learning dependent on the situation, for example, an MPharm student participating in pharmacy practice sessions (Brown *et al.*, 1989; Jonassen, 1991b). The learning process can be improved by increasing the learner's exposure within specific learning scenarios, i.e. MPharm students participating in more authentic practices common in community or hospital pharmacy and their subsequent interactions with patients and medicines, as opposed to learning just the theory of counselling and patient interaction in a classroom or workshop. Furthermore, as the constant changing of the meanings of given words alters a learner's current understanding, concepts will continue to develop (Ertmer

and Newby, 2013). Therefore, it is critical that learning takes place in a setting that is relevant to the material and relevant to the individual experiences of the learner. Consequently, AR educational tools and the lens from which this thesis is written may be considered within constructivism (Lim and Habig, 2020). AR can affect the relationship between the learner and their environment so that it may become situationally interactive and academically relevant.

1.5.1 Learning theories in practice

Education in both post-16 and undergraduate settings has mainly taken elements from the three categories of learning theories discussed above. Behaviourist elements may be more evident in post-16 education rather than undergraduate education. Although both types of learners require direction in their education, learners in post-16 settings may require a greater degree of support and direction in their studies from their educators (Bates, 2016). Undergraduate students may be deemed to be more independent in their study requirements. Independence may not be apparent at the beginning of university, but students may, as expected, quickly transition to taking responsibility for their learning; however, not all students use the initiative to do so. The principle of stimulus-response is a behaviourist technique used in post-16 and undergraduate education where learning is linked to a stimulus and response (Efgivia *et al.*, 2021). For example, lectures and presentations outline the topics educators deem to be important to the curriculum, which is then supplemented with problem exercises, quizzes, study guides, group projects and case studies that reinforce examinable material and, at the same time, convey the range of suitable responses and problem-solving strategies (Peters and Higbea, 2012). During the assessments, learners are conditioned to replicate the conditioned strategies and responses

rather than probing their knowledge for the optimal methods to analyse and appropriately respond (Peters and Higbea, 2012, 2014). The educator is perceived to assume primary responsibility for the learning process as they identify the relevant material and provide the range of responses and strategies; subsequently, learners passively acquire their knowledge. With that understanding, the learner's academic success can be associated with the educator's teaching skills (Peters and Higbea, 2012).

Cognitivist learning theories may have had the most profound effect on education, shifting away from teacher-centred methods and towards learner-centred approaches. As a result, cognitive learning theories are prevalent in post-16 and undergraduate education. The curriculum designs have become more flexible with continuous assessments, group-based learning and integration of applied practices. Mental imagery, problem-solving, and decision-making skills have all been impacted through cognitivist methods.

Constructivist teaching methods may be more apparent in undergraduate pharmacy education over post-16 education through experiential learning, examples of which are interprofessional education (IPE), hospital and community pharmacy placement opportunities, pharmacy practice sessions, pharmaceutical laboratory classes, series of group projects and reflective continued professional development (CPD) exercises. These exercises and teaching sessions require learners to interact with their experiences and environments to learn stipulated material on the curriculum but make meaning of the material in their own way. Piaget is probably one of the most recognised constructivist theorists, and his theory detailed how learners: react differently according to their stage of development, should be encouraged to learn from one another, should be allowed to make

mistakes with focus placed on the process of learning and the outcome, and learn with teachers providing a mentoring role towards students while respecting their interest, abilities and limits (Bates, 2016). A great example of this would be pharmacy practice sessions where learners practice drug dispensing and their counselling skills, sometimes on one another, in a controlled simulated environment. The emphasis is placed on learning, with mistakes having little real-world implications. Educators provide a supportive role, offering individual and group feedback that details critical learning points and objectives for students to take on board and improve.

Additional educational theories often used in biology, chemistry and pharmacy HE are Kolb's Experiential Learning Cycle, Bloom's Taxonomy and active learning, which are discussed in the following sections 1.5.2 to 1.5.4.

1.5.2 Kolb's Experiential Learning Cycle

Kolb's Experiential Learning Cycle (ELC) is probably the most well-known of the constructivist learning models and also an approach to incorporate elements of experience-based learning in education. The theory provides the rationale for several different learning methods contributing to its great appeal with educators – independent learning, work-based learning, problem-based learning and learning by doing (Gibbs, 1992; Henry, 1989). According to Kolb, knowledge results from an interaction between theory and experience (Dunlap *et al.*, 2008; Kolb, 1984).

> "Learning is the process whereby knowledge is created through the transformation of experience…" (Kolb, 1984, pg 38).

The ELC was based on previous work done by Dewey (1938) and Lewin (1951) (Naeem Akhtar, 2020) – a theory that comprehensively offers the foundation for a lifelong approach to education and learning. Kolb's ELC requires an active contribution from the learner as opposed to older, more conventional didactic approaches, which focus on teacher-directed instruction (Clark *et al.*, 2010). The ELC is broken down into four stages, as shown in figure 1.4 below. Complete learning is said to occur when the learner has gone through all four of the learning cycle's stages.

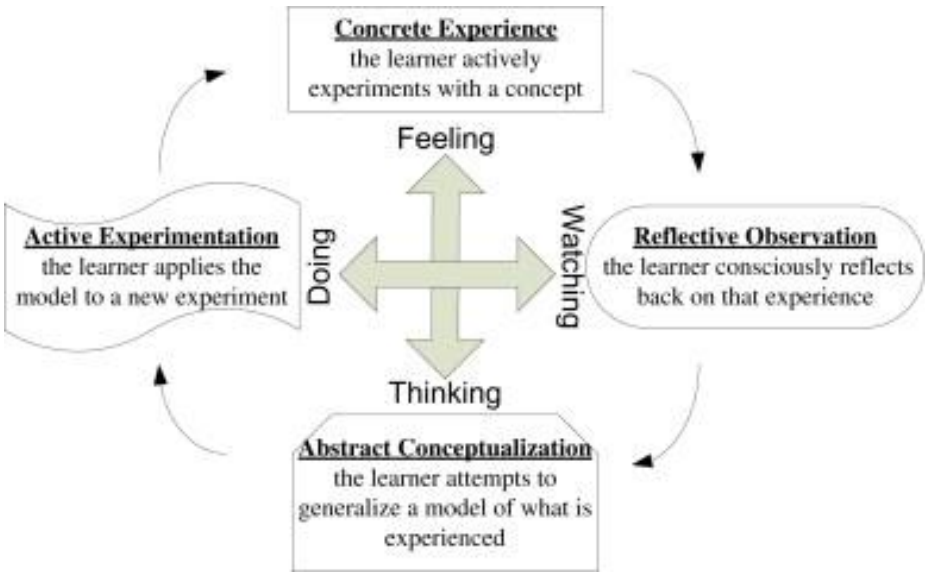


Figure 1.4 Kolb's Experiential Learning Cycle. Taken from Konak *et al.*, (2014)

Although learners can enter the cycle at any of the four stages, most enter at the 'concrete experience' stage, referring to the direct hands-on experience a learner gains from completing a new task. These experiences form the foundations for the following two stages, where the learner consciously reflects on their experience (reflective observation) and then attempts to conceptualise a model or theory for what they have experienced (Abstract conceptualisation). The final stage of the cycle occurs when the learner attempts

to apply and test their learning in new upcoming experiences (active experimentation) (Kolb, 1984).

The individual learner's ability, environment and learning history are reflected in their particular choice of learning style (Nulty and Barrett, 1996). When learning material is presented in a way that is coherent with the learner's preferred learning style, the student is said to learn more efficiently. Every learner is suited to a particular learning style; however, learners will still respond to and require input from all learning styles in one capacity or another. Kolb argues for the encouragement of learners to engage in all four stages of the ELC, as evidence suggests that learning is enhanced as more learning stages are completed (Smith and Kolb, 1986).

One of the main criticisms of Kolb's model is that learning does not always follow a typical sequence of definitive steps or stages, but rather the steps overlap or transition from one to another (Forrest, 2004). These criticisms, although fair, do not deter educators from acknowledging the benefits that the ELC can provide when accompanied by hands-on activities. Literature has documented how the ELC has often been used to analyse the differences in learning styles of several student groups in both field studies and classroom settings (Abdulwahed and Nagy, 2011; Clark *et al.*, 2010; Kulturel-Konak *et al.*, 2011). When used in field studies, the ELC has been shown to improve students' learning process; however, it has been known to take several weeks to complete the entire cycle (Clark *et al.*, 2010; Raschick *et al.*, 1998). With respect to classroom activities, however, literature is somewhat limited. Svinicki and Dixon (1987) and Stice (1987) have both recommended the use of Kolb's ELC to design classroom activities. In relation to ELC, chemistry, biology, and

pharmacy education application may best be used in instances where students undergo field trips (post-16) and community and hospital pharmacy placements (undergraduate). The real-life experience places the learner at the 'concrete experience' stage of the cycle. Once the placement or field trip is complete, learners then progress to the next stage, where they reflect on their experiences and form models of their experience that they can use in coming placements or field trips.

Each of the four steps of the cycle has also been linked to stages of another educational learning theory, Bloom's Taxonomy, explored in the next section (1.5.3) (Sivalingam and Yunus, 2017). The concrete experience, reflective observation, abstract conceptualisation and active evaluation stages are equivalent to Bloom's Taxonomy's applying, analysing, creating and evaluating steps.

1.5.3 Bloom's Taxonomy

Bloom's Taxonomy, also referred to as "Taxonomy of Educational Objectives", was a framework published by Bloom and a number of collaborators in 1956 (Armstrong, 2016; Bloom *et al.*, 1956). The framework has been utilised by generations of tutors for the education of infant all the way to adult learners. The original taxonomy consists of six major stages representing six cognitive levels ranging from simple to complex; knowledge, comprehension, application, analysis, synthesis and evaluation (Agarwal, 2019). Each of the different stages have been considered to be a stepping stone to the next and as a result, educators have often encouraged learners to progress to a higher level of thought, from one stage to the next - before comprehension, application or analysis of a concept learners must first acquire the knowledge of that concept (Agarwal, 2019; Forehand, 2010).

Although the original taxonomy was extremely popular, it has undergone multiple revisions and been interpreted in a number of ways to account for its limitations. Most notable of which published in 2001 by Anderson *et al.*, (2001). This revision included both terminological and structural changes evident in figure 1.5.

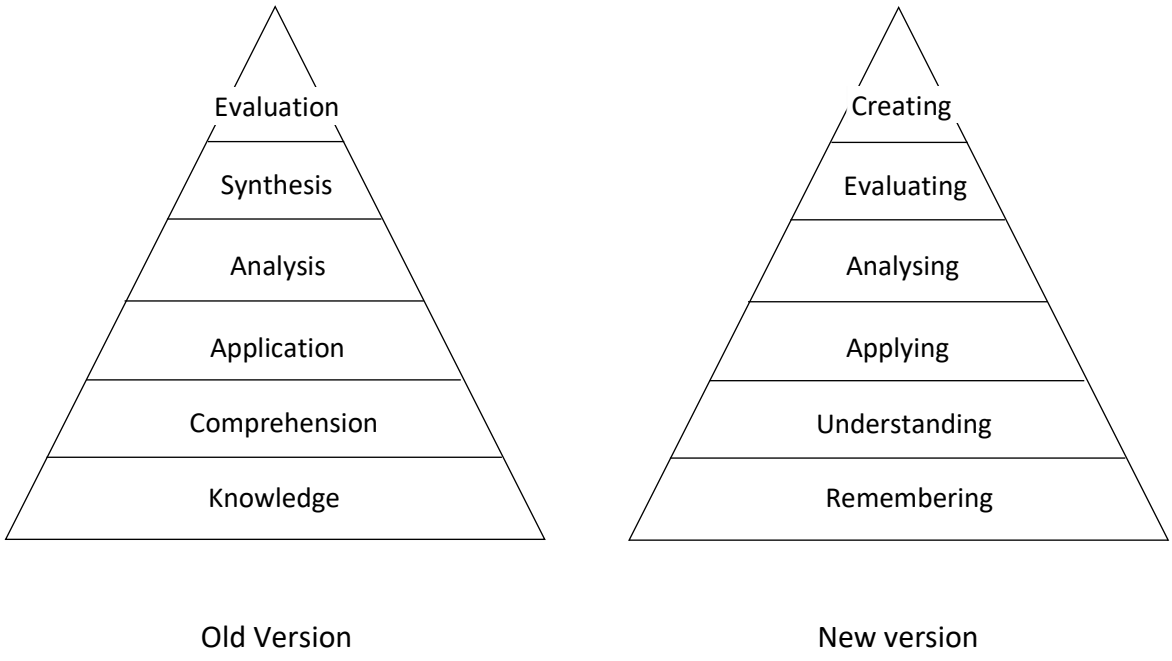


Figure 1.5 displays the changes in terminology and structure between the original and new versions of the Taxonomy (Forehand, 2010)

The most notable revision was the change in category names from nouns to verbs, and even more specifically the knowledge, comprehension and synthesis stages were changed to remembering, understanding and creating, respectively. With respect to structure, the new taxonomy takes the form of a two-dimensional table as opposed to the original singular dimension. The first dimension addresses the kind of knowledge learned (knowledge dimension) while the second identifies the process used to learn (cognitive process dimension) (Anderson *et al.*, 2001). The knowledge dimension consists of four elements (factual, conceptual, procedural, and meta-cognitive) whereas the cognitive process

dimension is subdivided into six elements (remember, understand, apply, analyse, evaluate, and create. Each of the knowledge dimensions can be further broken down, each into three or four categories. Similarly each of the six cognitive process dimensions can be further divided into eight categories each (Armstrong, 2016; Forehand, 2010).

The Cognitive Process Dimension						
The knowledge dimension	**Remember**	**Understand**	**Apply**	**Analyse**	**Evaluate**	**Create**
Factual knowledge	List	Summarise	Classify	Order	Rank	Combine
Conceptual knowledge	Describe	Interpret	Experiment	Explain	Assess	Plan
Procedural knowledge	Tabulate	Predict	Calculate	Differentiate	Conclude	Compose
Meta-cognitive knowledge	Appropriate Use	Execute	Construct	Achieve	Action	Actualise

Table 1.1 summarises the two-dimensional revised take on Bloom's Taxonomy. *Copyright © 2005 Extended Campus – Oregon State University https://oregonstate.edu/instruct/coursedev/models/id/taxonomy/#table Designer/Developer – Dianna fisher

Bloom's Taxonomy filled a void by providing educators with one of the first systematic classification of the process of learning and thinking (Agarwal, 2019). Each step of the framework requires the achievement of the prior ability or skill before progression to the next, more complicated step. The table (1.1) above details a clear visual representation between standards and the educational goals, objectives, and activities (Krathwohl, 2002). The table can be used to clarify the suitability of each lesson plan purpose, goal, or objective.

Pungente and Badger (2003) detailed how Bloom's Taxonomy can be used to support the teaching of organic chemistry. They recognised instructors often quickly transition into a "higher-level cognitive gear" delving into the applications of organic chemistry concepts

while students are stuck at the remember and understand cognitive stages, memorising what would seem to be unrelated facts. Pungente detailed the execution of Bloom's Taxonomy to help students identify what level of the taxonomy they would need to work or function at to succeed on the course. Students were informed of the importance of progressing beyond the remember and understand levels and that they would be tested beyond this stage of the taxonomy – it was in their best interest to look for patterns between mechanisms and fundamental chemical principles to compare and contrast, developing their personal mental framework of organic chemistry. Students benefitted even further through the actions of their instructors, placing emphasis on what cognitive level students should view the material when in lectures. Ultimately helping students gauge the expectation level of examination and assignments.

Many of the limitations seen in the original taxonomy have been address in the revision presented by (Anderson *et al.*, 2001). One of which was the assumption that the cognitive process was ordered into a single dimension cumulative hierarchy of simple to complex behaviours (Furst, 1994, pg. 34). Case (2013) reported a further limitation of the taxonomy that would halt a learner's progression, that being a learners capacity to think beyond a given sequence and the inability to recall content. If learners are unable to achieve the most basic stage of Bloom's Taxonomy, there would be little hope to reach the application/applying or synthesis/evaluation stages(Case, 2013). The revised taxonomy must also acknowledge recent developments in educational theory. At the time of its construction, behaviourist learning theories dominated educational practises and as explained in section 1.5. Since then, the emergence of constructivist learning theories such as active learning (explored in the following section (1.5.4) which places a larger

responsibility of learning on the learner, as a result the revision of Bloom's Taxonomy would require further amendments (Amer, 2006).

1.5.4 Active Learning

Active learning, a constructivist theory, represents a pedagogy that includes any instructional approach that actively engages the learner as opposed to just passively listening, aiming to improve the learning process. This may be deemed as a general approach, but more specific methods are present in a variety of disciplines in secondary and HE – biology (McClanahan and McClanahan, 2002), mathematics (Inch, 2002) and communications (Schwebel and Schwebel, 2002). The intricacies of active learning methods may differ from one another, but Kane (2004) identified four key characteristics: (1) critical thinking should be encouraged; (2) the responsibility for learning is placed on the learner; (3) engagement in open-ended activities; and (4) the educator should organise the learning activities.

There are several different active learning techniques today, some simplistic and others more versatile and multifaceted. As McClanahan and Wicks (1993) described, Debriefs require the instructor to lead discussions of an interactive student session to validate and correct incorrect responses. Such techniques allow students who may not have responded to questions to learn the correct answers. The 'think, pair and share' technique involves pairs of students formulating a joint response to a question. All pairs will then share their responses with the entire cohort, and if needed, the instructor will provide the correct or expert response (King, 1993). Slightly more complex techniques include the BSCS matrix (McClanahan and McClanahan, 2002) and partial outline (Angelo and Cross, 1993). The

matrix approach requires students to use learning material they have been taught in a completely different style to which it was delivered. This method requires individuals to use higher thinking skills while focusing on key concepts. The Partial outline technique builds students' note-taking and outlining skills. The focus is placed on the main topics as students complete a summary of what was covered in a recent teaching session.

Problem-based learning is a more modern and popular active learning technique in healthcare education (Camp, 1996). Students are grouped and work to investigate scenarios presented by the instructor. Each student is required to conduct and complete different elements of the project to solve the issue. The group conducts ‘research’ outside the teaching sessions, and members share their information within the class when the cohort returns. Another form of active learning is brainstorming exercises where learners a required to generate ideas about a concept, and all responses are accepted and noted on a board or poster. This method often introduces topics and assesses learners' understanding of the subject area.

A proportion of postgraduate and, to a degree, undergraduate healthcare training occurs in the workplace, and as a result, it can often be difficult and time-consuming for educators to organise, expensive, as well as being associated with an element of risk (Bivall *et al.*, 2021; Brammer, 2006). In addition, the learner may describe the experience as daunting, knowing how complex and overwhelming a working environment can be. Nevertheless, to achieve high professional standards, healthcare students are required to undergo training in natural world settings – the training should enable the knowledge of competencies gained in theory and practice scenarios to be transferred into the real world. For this to occur, a learner must

undergo meaningful learning. Meaningful learning can be described as (Perkins and Salomon, (1999) and Jonassen, (2008)):

- Active – 'learning by doing' requiring interactions with the real world.
- Constructive – integrating new experiences with already experienced knowledge.
- Intentional – behaviour directed by goals and targets.
- Authentic – implements real-world tasks where the complexity changes within a realistic environment.
- Cooperative – requires communication and collaboration.

For education at any level to progress, teaching methods must be accompanied by active learning elements and interactive pedagogies (Armbruster *et al.*, 2009). A 2011 Horizon report proposed that AR would be introduced within two to three years as a form of active learning and create new opportunities for teaching, learning, research and creative inquiry (Johnson *et al.*, 2011). Although the prediction did not commercially materialise, researchers have explored the potential uses of AR in education and training. For example, Linn's 2013 review demonstrated how researchers diligently explored technology-aided learning and the trend to develop AR tools to aid spatial visualisation. Similarly, Rutten *et al.* (2011) discussed the advantages of learning with a computer-generated system. Such a dynamic can support the learner in visualising phenomena and manipulating experimental variables that would otherwise be inaccessible in the real world.

1.6 Educational Technologies in Science

Technology has and continues to play a pivotal role in education and the learning process, especially forms of technology that supplement and blend reality like computer simulations

and AR (Baek *et al.*, 2008; Bransford *et al.*, 1999; Bruce and Levin, 2003). The relatively fast development and widespread availability of information technology have given rise to societies that heavily depend on creating, distributing, and manipulating information. Thus, these modern societies must align with the most recent technological advancements. The surge in information and increased number of students in education (Keser, 1988) created issues that educational technology aimed to correct. Information has now become easier to find, access and store, thus streamlining the educational process and contributing to the higher quality of teaching in educational institutions (Cabaleiro-Cerviño and Vera, 2020; Keser and Özcan, 2011). Technology in education has allowed learners to partake in network or cooperative learning (student-student and teacher-student interactions) at a greater frequency than before and serve as sources of information (Norris and Coutas, 2014). Universities, in particular, incorporate technology for two main reasons – first, Information and Communications Technology (ICT) represents innovation in learning methods that can promote new goals for its use as universities wish to be seen as leaders in the application of new training methods; and secondly, developments in the use of ICT encourage the formation of alternative learning pathways such as self-learning, distance learning and, two-way communication systems (Cabaleiro-Cerviño and Vera, 2020; Hamiti *et al.*, 2014)

The role of the tutor when incorporating educational technology in classrooms is essential. Although educational technologies support the students' learning, they can be constructed to take the place of real-life educators. For example, online platforms/services provide a comprehensive programme of material for learners to work through independently. The platform can be constructed, so physical educators are not necessary for learning (VanLehn,

2011). In these instances, tutors may provide additional support that can direct the learners' interaction with the educational technology. Throughout teaching sessions, it would not be uncommon to see the tutor explain how particular education technologies can help their learning. As the learner matures, they may begin to ascertain which educational technologies best suit their needs and provide the best support. Educational technologies, particularly advanced digital technologies available today, support learners in facilitating self-directed learning (Bonk and Lee, 2017; Rohs and Ganz, 2015). However, a scoping review by Morris and Rohs (2021) found a key theme of co-responsibility. Learners who had primary responsibility for their learning process received support from either an educator or fellow learners. They concluded that regardless of how detailed the educational tool was, learners would still require the support of an educator or peer. It should be noted that these students were in primary education and, therefore, less academically mature than adult learners who may not require as much support.

Educational technology may be used to improve the efficiency of a student's learning process (Bransford *et al.*, 1999; Cabaleiro-Cerviño and Vera, 2020). Computers and similar devices may offer technology-inclined individuals a more attractive environment to develop; however, educator and learner literacy in information and communication technology (ICT) are crucial for its success. With sufficient ICT literacy, digital educational technologies can empower students to critically analyse information, communicate, collaborate, and problem-solve (Keser and Özcan, 2011). Educational technologies are viewed as the future of teaching and learning and can potentially drive effective educational learning. When coupled with conventional teaching, these devices can have a number of desirable effects for both tutors and students - improved impact in both the cognitive and

affective domains has been associated with improved motivation, higher productivity, improved instructional abilities and the development of new ICT skills (Makhlouf and Bensafi, 2021; Nilsen and Purao, 2005; Roblyer, 2006; Roblyer and Edwards, 2000).

Instructors and tutors will usually encourage learners to interact with the technologies in particular ways so that they will mimic the particular aspect of their studies. Within science, technology, engineering and mathematics (STEM) subjects, tutors will use particular educational tools conducive to the delivery style of specific educational content; this includes how they wish for students to interact with the educational material (Wu *et al.*, 2019). For example, students of STEM subjects often struggle with the phenomenon of translating physical 3D and virtual 2D representations. The exercises are challenging as they require learners to understand specific features of each representation and then make connections between them (Ainsworth, 2008; Kozma, 2003; Rau, 2017; Stull *et al.*, 2012). This reasoning has resulted in tutors using educational technologies that can ease this learning process - AR is a sort of educational technology that focusses on the challenging aspects of translating 3D and 2D representations.

1.7 History of Augmented Reality

AR has been defined in many different ways by various researchers. A broad definition coined by Azuma *et al.* (2001) was; “the supplementation of the real world with computer-generated content, such that the two worlds seem to coexist.” Azuma continued and identified three main individualities that contribute to AR: (1) an amalgamation of real and virtual objects and structures in an authentic setting, (2) the ability to interact in real-time and (3) both real and virtual objects and structures are aligned with one another.

Implementing an AR system is brought about through technology that can merge real and virtual information in a purposeful manner that fulfils the three individualities Azuma identified. More recently, devices such as smartphones, tablets and wearable computers encompass the necessary capabilities to fulfil the needs of AR (Klopfer, 2008). Early versions of AR systems implemented wearable head-mounted displays (HMD). For example, Caudell and Mizell (1992) used an early version of an AR system to investigate its effectiveness in the aerospace manufacturing industry. An HMD unit, head positioning and workstation registration systems were used. Initially, such systems required sophisticated equipment with excellent processing power to create an AR environment. However, developments and breakthroughs in the graphical processing power of computers, coupled with the rise of quality mobile devices, have afforded AR systems increased portability, high social interactivity features through networked devices and face-to-face interactions, improved ability to display text relevant to the user's need, and independent operability, ultimately contributing to an immersive experience (Chiang *et al.*, 2014; Dede, 2009). Such advancements contributed to developing better-quality HMD AR devices such as the Microsoft HoloLense™, Google glass and EyeTap. The developments are not limited to wearable devices but also stretched to flat panel display mobile devices such as Pokémon Go, AR EdiBear or AR Tower Defence (Raja and Calvo, 2017).

1.8 Types of AR systems

AR systems can be classified as either single-user systems, where the individual user is effectively in a separate AR environment or a multi-user collaborative system, where multiple users are linked and can interact with one another in a single environment (Lebeck

et al., 2018). Both systems have been applied to many industries, including science, entertainment, training and engineering (Azuma, 1997; Hincapié *et al.*, 2021; Shin *et al.*, 2010; Shuhaiber, 2004). Most AR systems are classed as single-user systems, but there are instances of multi-user systems, such as the StudierStube developed by Schmalstieg *et al.*, (2002). Multi-user AR systems afford users to interact with the same virtual content as other users in real-time, sharing the common experience. However, disturbances to the shared network can disrupt its seamlessness nature and detract from the experience (Apicharttrisorn *et al.*, 2020; Ran *et al.*, 2019). On the other hand, single-user systems do not require inter-device networking features to provide a smooth, engaging experience.

Additionally, AR systems are classified through the process in which virtual information is displayed to the user. This occurs in two ways: the systems will require the recognition of either unique markers/images ('Image-based AR') or recognition of the user's position within a defined location ('location-based AR'). Once detected, the virtual information assigned to the image or location is superimposed onto the users' view of the real world. Early forms of such systems involved embedding several unique images/markers within books. A webcam connected to a desktop computer captured the marker and displayed the associated virtual image on the screen for an audience to view. For example, Martín-Gutiérrez *et al.*, (2011) study involved an AR book, webcam and projector to help develop the spatial abilities of engineering students. The virtual image was displayed through the projector as though it rested upon the pages of the textbook. This setup was replicated in additional studies that involved students in classroom settings (Kerawalla *et al.*, 2006; Núñez *et al.*, 2008). In each instance, the students could view the virtual image through many perspectives by rotating the book, which in turn rotated the virtual image. Núñez *et*

al., (2008) found a great level of acceptance from users and improved performance in correctly solving organic chemistry questions. Kerawalla (2006), on the other hand, found that their AR book was less engaging to students compared to traditional recourses; This study found educators were more likely to ask participants to watch and describe the AR animation as opposed to participants in the control group whom role played scenarios. The constraints of desktop computers no longer bind image-based AR due to the introduction of mobile devices. Such devices detect the unique image in the same way as the webcam-computer system but are far less cumbersome. Image-based systems are not limited to detecting markers embedded in textbooks; however, this is where they are more commonly found in addition to markers embedded in playing cards, such as the tool evaluated in this research, Pharma Compounds.

'Location-based' or 'markerless' are terms used to describe AR systems that rely on a wireless network or geological positioning system that tracks the user's position (Dunleavy and Dede, 2014). As with image-based AR systems, a camera captures the user's view of the real world but relies on a wireless system that identifies the device's position within a designated area to display the superimposed virtual image. Usually, the virtual information is fixed in a specific location; it is then up to the user to move around this specific point to view the superimposed structure from various angles. This form of AR is most commonly used at historical sites, museums or tours of complexes and cities to display archaeological and historical content (Gleue and Dähne, 2001; Lee *et al.*, 2012; Vlahakis *et al.*, 2002; Yovcheva *et al.*, 2012). Feiner *et al.*, (1997) showed how an outdoor location-based AR system could guide and assist users in exploring and providing historical information about a location, such as older versions of buildings and structures. This early system consisted of a

wearable backpack that displayed virtual information to the user via a wearable headset. McCall *et al.*, (2011) developed a location-based AR game using handheld mobile devices to display the virtual information where users were immersed in an explorative experience whereby moving from one region of a city to another resulted in different virtual information being displayed – The virtual information being text, 3D models, sound or graphs that related to the history of the city. The GPS or internet system in location-based AR offers real-time information, whereas image-based AR relies on recognising unique markers. Following the recognition process, both forms of AR can present the same types of virtual data (3D models, text, audio, video, graphical content), supplementing the view of the real world.

Mobile devices have made massive strides in functionality and performance by utilising better hardware and more powerful software programs. Coupled with a reduced-price tag, mobile devices such as smartphones and tablets have now made AR widely more accessible. Many industries, including marketing, entertainment, manufacturing, and urban design/construction, have adopted AR to enhance the viewing and working experience (Raja & Calvo, 2017). For example, MINI used AR to showcase their new car and engage customers during the 2008 advertisement cycle. Customers could scan the advertisement section with their webcam, and a virtual MINI would appear on the screen (Berryman, 2012). In entertainment, AR has been used in media, gaming, and museums. Games such as ARhrrr! Skyinvader and ARQuake included AR to bring the gaming experience to life (Kroeker, 2010). With respect to urban design and construction, AR has been used to provide real-time visualisation of projects and structures and improve collaboration between architects, engineers and the building trade, aiding those unable to read drawings

and schematics (Heinzel *et al.*, 2017). Location-based and imaged-based AR systems have greatly used mobile devices' capabilities and features (high-resolution camera, GPS tracking, and object recognition tracking), contributing towards an immersive experience (Dunleavy & Dede, 2014).

1.9 AR in Education and Training

Although AR has been shown to be a promising addition to education and a tool that could facilitate the development of newer pedagogical methods, its initial integration into educational settings was challenging (Johnson *et al.*, 2011). Costs of development, maintenance and a lack of ICT literacy from educators may have hindered its progression. Only recently had the explorations into adaptations of AR systems been fruitful enough to combat these issues and given rise to formats and styles of AR systems that can be specifically designed for education and training (section 1.7).

There are instances documented in the literature where experimental AR systems had been developed and applied to educational settings, and showed great promise. For example, Martín-Gutiérrez *et al.*, (2010) utilised an image-based AR system to aid the spatial development of engineering students. Their application incorporated unique markers embedded in what is referred to as a 'Magicbook'. The accurate positioning and rotation of the marker were registered by a webcam linked to a computer and resulted in the generation of 3D virtual geometry on screen as though they rested on the pages of the Magicbook. Participants could manipulate the 3D models by tilting and rotating the book to have a viewing perspective from various angles. This study found that learners who used the AR Magicbook system significantly improved their spatial skills and correctly identified

vertexes and surfaces on orthographic and axonometric views of objects compared to the control group who had not undergone AR spatial training.

A 2006 study found evidence to support the use of AR in education, as teachers acknowledge the benefits 3D imagery can bring to the classroom. Participants believed AR provided the opportunity to explore subject material that would otherwise be inaccessible (Kerawalla *et al.*, 2006). It was noted, however, that some participants anecdotally seemed to be less engaged in AR teaching sessions compared to traditional teaching sessions. Interviews revealed that educators believed reports of low engagement were due to the speed at which the animations were played. They suggested additional functions to control the model speed would improve engagement. This study did not compare the effectiveness of manipulating physical objects to using 3D models. However, an earlier study by Copolo and Hounshell (1995) found that the combination of both physical and computer-generated models increased learners' performance compared to the performance of learners who solely used physical models. Therefore, they suggested that AR systems should not completely replace physical models but should be used in conjunction to accommodate different learning styles (Wu *et al.*, 2001).

Superimposing computer-generated imagery onto physical objects has been reported to provide unique affordances in visualising otherwise unobservable phenomena such as airflow and magnetics fields (Dunleavy *et al.*, 2009; Klopfer and Squire, 2008; Wu *et al.*, 2013). Fjeld and Voegtli (2002) developed an AR system (Augmented Chemistry) that consisted of a table and rear projector screen. Below the screen sat a camera that captured the user’s interaction with the AR markers. The onscreen projection would then display

what was captured by the camera with the additional virtual imagery, almost as though it were a mirror. The Augmented Chemistry system allowed users to choose a chemical element, compose a 3D model and then examine the model by rotating the 3D marker. An AR paper-based colouring book developed by Clark, Dünster and Grasset (2012) provided young children with a unique visual experience where different 3D models were displayed depending on the colour they decided to colour the pictures in the book.

Virtual environments often possess unique traits of immersion, immediacy and presence (Dalgarno and Lee, 2010; Witmer and Singer, 1998). Kotranza *et al.*, (2009) have liked these traits to multi-user AR systems. They suggested that including real-time text and feedback offered a sense of immediacy in an AR learning scenario. When learners, virtual information, object, and characters in the real world are brought together, they contribute to an enriched learning experience that may encapsulate aspects of presence, immersion, and immediacy. A 2012 study encapsulated these elements and found a significant correlation between changes in nuclear attitudes and the perception of the AR activity among grade nine students (Chang *et al.*, 2013). Students used handheld tablet computers to gather simulated AR radiation data on the Fukushima Daiichi Nuclear Power Plant. Students understanding of science content was promoted by using mobile AR in the inquiry-based pedagogy. The style of the study made it possible for students to be situated in the campus environment (presence), was enhanced with the use of physical objects and virtual images (immersion) and aimed to effectively mimic the real events of the scenario (immediacy). Change and his colleagues found reason to believe the changes in students' perception towards socio-scientific issues were associated with their views towards the AR activity.

As mentioned, AR systems are far more compact and streamlined than early editions (section 1.7). Mobile devices with connectivity and GPS capabilities can facilitate situated AR learning that is both pervasive and collaborative (Dunleavy *et al.*, 2009). 'Environmental Detectives', a location-based AR game, was developed to support learning outside of a classroom. Handheld devices were used to investigate specific environmental scenarios; students gathered data at specific locations at their school and analysed and interoperated the information. The study found that by engaging students in an AR game in real time and space, there were correlations between improved context sensitivity and the making of a well-informed decision in relation to environmental issues (Klopfer and Squire, 2008). A particular issue associated with using handheld AR devices (smartphones and tablets) is related to task interruption and distraction and the drawback that may have on learning. It was suggested that location-based AR systems could potentially counter this by tracking students' location and work progress via GPS or sending task reminders for users to refocus should they become distracted (Roda and Thomas, 2006).

Lastly, AR educational tools have been associated with connecting informal and formal learning environments. The CONNECT system coupled elements of AR with other technology and additional exercises to create a virtual science thematic environment. Although the full capabilities of this educational AR tool had not been measured, an early study suggested it showed positive influences on students' motivation towards learning science and the understanding of friction as a concept (Sotiriou and Bogner, 2008).

Many of the AR educational tool examples above demonstrate the technology's alignment with the constructivist educational method. Learners were described, to a certain extent, to have taken responsibility for their learning and used the AR tools to explore either their environment or phenomena from a perspective of personal interest – thus forming new meanings of and interacting with their environments to form new knowledge (Kerawalla *et al.*, 2006; Martin-Gutierrez *et al.*, 2010; Sotiriou and Bogner, 2008). The level of immersion and immediacy generated in AR environments supports its standing in situational learning scenarios and other constructivist methods. As Kotranza *et al.*, (2009) reported, real-time information and feedback in AR systems lead to immediacy, which can enrich learners' educational scenarios.

Despite the affordances brought to science education by AR systems, they are not unique to AR. Although other teaching methods and learning environments that utilise similar technology and concepts may also be associated with similar benefits, it has been suggested that AR systems should be aligned with varied instructional approaches to explore and maximise the proposed educational objectives (Bronack, 2011).

1.10 Introduction to the Study and Organisation of the Thesis

The scope of this study was to evaluate the effectiveness of an educational augmented reality mobile app in the education of students undertaking similar learning (sixth form biology and chemistry students and second year pharmacy students).

Literature surrounding augmented reality in biology, chemistry and pharmacy HE is explored in a narrative synthesis review presented in Chapter 2. Chapter 3 detailed the aims and

objectives of this study. This research programme employed a mixed methods approach incorporating both quantitative and qualitative elements; the theoretical reasoning behind the methodological approaches and methods used in the study can be found in Chapters 4 and 5, respectively. The design and development of the educational AR intervention are discussed in Chapter 6. Results obtained from the quantitative and qualitative elements of the study are presented in Chapters 7, 8, 9 and 10. Finally, the thesis discussion can be found in Chapter 11, where the concluding remarks for this study are made, along with its limitations and implications for future research.

2 Literature Review: Narrative Synthesis

2.1 Introduction

This chapter presents the systematic search and narrative synthesis of literature focussed on using AR educational tools in chemistry, biology, and pharmacy higher education. The chapter begins by exploring the types of literature reviews commonly encountered (section 2.2), followed by the aims of this literature review (section 2.3). Section 2.4 details the process by which literature was selected for this review; this includes the eligibility criteria (section 2.4.1), search strategy and data sources (section 2.4.2), study selection process (section 2.4.3), and data extraction process (section 2.4.4). The findings of the systematic search are detailed as a narrative synthesis in section 2.5. Next, an overview of the results is described in section 2.5.1, followed by a discussion of the identified themes in sections 2.5.2 to 2.5.5. Finally, the limitations and quality assessment of the studies included in this review are discussed in section 2.6 before the chapter summary in section 2.7.

2.2 Types of literature reviews

Advancements in research occur when prior studies are methodically synthesised based on the findings and conclusions made by researchers in the past (Kumar *et al.*, 2020). Literature reviews are critical evaluations of published studies that come in many variations, but all contribute to the conceptual, methodological, and thematic developments of research areas (Bem, 1995; Snyder, 2019). Review pieces, most commonly systematic reviews with or without the inclusion of meta-analyses, strategically isolate and compare multiple studies to provide readers with an understanding of a specific research area and highlight gaps for potential future work (Marabelli and Newell, 2014).

Literature reviews generally take on two broad forms; a background review for an empirical study or a stand-alone piece (Templier and Paré, 2015). The former is most commonly used to provide a rationale for a research design, contribute towards the theoretical context, or, as already mentioned, identify gaps in the research literature that can be explored by a proposed piece of research (Levy and Ellis, 2006). Stand-alone literature reviews, however, aim to develop an understanding of existing literature through aggregating, interpreting, explaining or integrating current literature and subsequently identify gaps for future research (Rousseau *et al.*, 2008). In addition, a section of literature from systematic reviews that relates closely to the empirical study can also be used as a background review. As such, stand-alone literature reviews can strengthen the quality of background reviews (Xiao and Watson, 2017).

Narrative reviews are the most commonly encountered type of descriptive literature review; however, they may be considered by readers to be the least rigorous as the process by which evidence is gathered may not have followed specific rules, or the process may not be explicitly reported in the resulting article (Collins and Fauser, 2005). The data extraction process for narrative reviews can be informal and are unlikely to be systematic. Therefore its discourse may be biased towards the reviewer's prior beliefs, experiences and overall subjectivity (Noordzij *et al.*, 2011). The lack of a transparent decision-making process may lead a reader to question the relevance or validity of included studies (Collins and Fauser, 2005). Nevertheless, narrative reviews can be generally comprehensive and useful when literature in the area of interest is varied (Green *et al.*, 2006). These reviews have been described to focus on gathering relevant information that provides context and substance in support of the authors' argument rather than assessing the quality of the evidence as with

other forms of literature reviews (e.g. meta-analysis) (Kastner *et al.*, 2012). Nevertheless, there are instances where authors may decide to appraise included articles for their quality, which can offer readers some credibility in their findings (section 2.6).

A narrative synthesis, different from a narrative review, is rooted among the 'descriptive' types of literature reviews and is typified by a standardised data extraction process that identifies several study characteristics (i.e., quality, findings, population, context). This systematic data extraction makes a narrative synthesis more rigorous than a standard narrative review. Lucas *et al.*, (2007) and Popay *et al.*, (2006) outlined the intricacies of a narrative synthesis and detailed how studies must be organised into more homogeneous subgroups before comparisons can be made between their similarities and differences. This type of review often has some quantitative elements due to the standardised coding format that details the number of studies that share the same particular feature or characteristic (Kastner *et al.*, 2012).

On the other hand, meta-analyses fall into the 'test' category of literature reviews. They commonly include large-scale randomised control trials (RCTs), requiring quantitative data extraction to conduct statistical tests on multiple independent but related studies. Following a systematic literature search, summary statistics common to each RCT are extracted to serve as the dependent variable. Usually, this is the effect size, with moderator variables as the independent variable (Stanley, 2001). In addition, meta-analyses typically include a meta-regression and an explanation of the results.

Ultimately, the type of literature review should be dictated by the research question and the available evidence, as every kind of review serves a different purpose (Collins and Fauser, 2005). Regarding this thesis, the scope of this literature review was to explore the variety of educational AR tools developed for chemistry, biology and pharmacy higher education, the methods used to evaluate them and to identify potential areas for future research. Therefore, a narrative synthesis was performed to review published literature surrounding educational AR tools in biology, chemistry, and pharmacy subject areas. Additionally, after a systematic search of the published literature, there was an absence of RCT's subsequently ruling out the possibility of performing a meta-analysis (Ahn and Kang, 2018). Therefore, a narrative synthesis was deemed most appropriate as it enabled focus to be placed on a wide range of questions and not only questions that related to the effectiveness or performance of a specific intervention, thus providing a more holistic scope of AR in the particular subject areas. Furthermore, this approach allowed for a systematic review and synthesis of findings from studies that relied mainly on using words to summarise and explain findings (Popay *et al.*, 2006). Furthermore, these findings could also be used to compare the findings of the Pharma Compounds AR educational tool evaluated in this research (sections 11.3 and 11.4).

2.3 Narrative review objective

This narrative synthesis aimed to identify what is currently known regarding the use of educational AR tools in biology, chemistry, and pharmacy higher education (level three to level seven qualifications or equivalent). Many literature reviews generally cover the use of AR technology in the education of infant, child and adult learners. These reviews mainly focused on STEM subjects such as mathematics, chemistry, physics, engineering, computing,

natural sciences, and biomedicine but did not explicitly review its use in pharmacy-related subjects (Chen *et al.*, 2017; Majeed and Ali, 2020; Vuta, 2021; Wu *et al.*, 2013). Therefore, the scope of this review focused on the use of AR in biology, chemistry, and pharmacy-related education, specifically at level three to level seven education as defined by the Department for Education (Department for Education, 2022). Although AR may have been reviewed in biology and chemistry subjects, no published literature review focused on its use specifically in higher education (level three to level seven or equivalent). By focusing on this level of education, more direct comparisons and similarities can be made between those included studies and studies that addressed AR's use in pharmacy-related higher education (level three to level seven).

An objective of this review was to identify and assess the effectiveness measures used on AR tools in the included literature. This included the assessment of the educational outcomes against which AR tools had been evaluated and the credibility of the tools used to measure said outcomes. Additionally, identifying the type of AR system used in the study, the education subject, the level of education and the data collection tools used formed part of the narrative synthesis.

2.4 Methods

Popay *et al.*, (2006) detailed guide for narrative synthesis in systematic reviews described how a review must document the identification, selection, appraisal and synthesis processes. The research question should guide each stage of the process to ensure a systematic approach is followed. This document and The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) updated 27-item checklist were used as a

guide for this review (Page *et al.*, 2021a, 2021b). The PRISMA protocol guided the process by which studies of different methodologies were included, as well as the reporting of the review – the checklist documents a series of features expected to be present in a systematic review that evaluates the effects of a common intervention. The systematic review guide by Popay *et al.*, (2006) detailed steps on three narrative review elements used in this review; development of the preliminary synthesis of findings, exploration of relationships between data and assessment of the robustness of the synthesis.

2.4.1 Eligibility Criteria

The PICOS (participants, intervention, comparators, outcomes and study design) approach detailed in the PRISMA 2020 explanation and elaboration document was used to guide the inclusion and exclusion criteria of this narrative synthesis (table 2.1) (Page *et al.*, 2021b). Articles were excluded from the search if student participants were not enrolled on biology, chemistry or pharmacy level three to seven courses, as mentioned in section 2.3. Studies that did not describe, depict (diagram), or provide a web link that detailed the format of the augmented reality intervention were excluded as function heavily depends on the intervention's design. Additionally, studies that only compared AR and virtual reality (VR) tools were excluded. Although different, AR and VR may provide similar affordances to learning, with the latter considered to produce a more immersive experience (Huang *et al.*, 2019). Both have been considered part of the same virtuality continuum where augmented reality is situated between reality and VR (Milgram *et al.*, 1994). Therefore, heavily augmented AR tools may be located on the continuum closer to VR extreme and would rely on the author's subjective opinion to categorise the educational tool as either AR or VR. Therefore, it was decided to remove studies that only compared AR and VR tools. Articles

were also excluded if they were not available in English, were conference abstracts, proceedings, presentations, or posters, and where the full text was not available online.

PICOS	Inclusion Criteria	Exclusion Criteria
Participants	Individuals who study biology, chemistry or pharmacy in HE (level three to level seven (Department for Education, 2022))	Individuals who are not biology, chemistry, or pharmacy HE students (level three to level seven(Department for Education, 2022))
Intervention	AR educational tools Studies that disclosed the type of AR educational tool used (explanation, diagram/picture, or weblink)	Studies that do not disclose the type of AR educational tool used (explanation, diagram/picture, or weblink)
Comparison	Studies that did or did not compare AR educational tools to other educational tools Studies that did and did not make use of control groups were included	Studies that only compare AR learning to virtual reality learning were excluded
Outcomes	Assessment tools Self-reporting tools	No outcomes reported
Study	Evaluation studies – including qualitative, quantitative, mixed methods studies	Studies that described the development of AR educational tools with no evaluation

Table 2.1 Details the inclusion and exclusion criteria used to screen studies based on the PICOS approach (Page *et al.*, 2021a, 2021b)

2.4.2 Search Strategy and Data Sources

An initial scoping review of the literature was performed at the beginning of this study (in 2017) to develop an insight into the published literature, identify possible gaps and help guide the research methodology. A systematic search was performed in November 2021. The databases included in the search are detailed in table 2.2.

Electronic Databases Used in the Narrative Review
Web of Science (1997 – 2021)
Science Direct (1991 – 2021
PubMed (2001 – 2021)
IEEE Explore (1997 – 2021)
EBSCO (1970 – 2021)

Table 2.2 Displays the databases that were searched in the systematic review process. All databases were searched from the earliest records available. The dates shown in the table display the range in which articles that include the search terms were published

The systematic search used the keywords below in combination with Boolean operators to search the title and abstracts of articles in each database. In addition, thesaurus or MeSH terms were used within each database to help expand the search strategy. Search term two was included in the systematic search strategy as the term 'mixed reality' had been used in place of AR and as an umbrella term used to define the result of combining physical and virtual environments in a spatially coherent manner (Holz *et al.*, 2011; Hughes *et al.*, 2005; Milgram *et al.*, 1994). This definition became a synonym for the description provided by Azuma *et al.*, (2001) and was accepted in Chapter 1.7 of this thesis. As mentioned in section 2.3, the scope of this review was focused on biology, chemistry, and pharmacy learners. There are several general literature reviews on AR in education; therefore, this review focuses on the education of chemistry, biology, and pharmacy students. Furthermore, the review's scope was angled towards these subjects in higher education resulting in keywords eight to thirteen. The term 'student' was favoured over 'pupil' and 'learner' in the UK Quality Code for Higher Education Framework for qualifications and was therefore used in the search strategy (QAA, 2014).

1. ‘augmented reality’
2. ‘mixed reality’
3. 1 OR 2
4. ‘pharmac*’ (to find pharmacy, pharmacist, pharmacology, pharmacodynamics, pharmaceutics, etc.)
5. ‘biology’
6. ‘chemistry’
7. 4 OR 5 OR 6
8. ‘student’
9. ‘higher education’
10. ‘undergraduate’
11. ‘sixth form’
12. ‘college’
13. ‘university’
14. 8 OR 9 OR 10 OR 11 OR 12 OR 13
15. 3 AND 7 AND 14

2.4.3 Study Selection

The articles from the systematic search strategy were imported into and managed using the Mendeley reference manager (Mendeley Ltd, 2020). The screening process began by reviewing the citations and removing duplicate articles. The title of each piece was then reviewed, followed by the abstract and the full text. Articles were included in the next stage of the review process if they met the inclusion criteria or a definitive decision could not be made at that stage of the review – if a final decision could not have been made at the full-

text review stage, a second opinion was obtained from the supervisory team. The figure below (figure 2.1) details the study selection process. Next, a literature search was carried out and each article was appraised. Finally, the literature search was augmented by hand with articles found through the screening references of included studies.

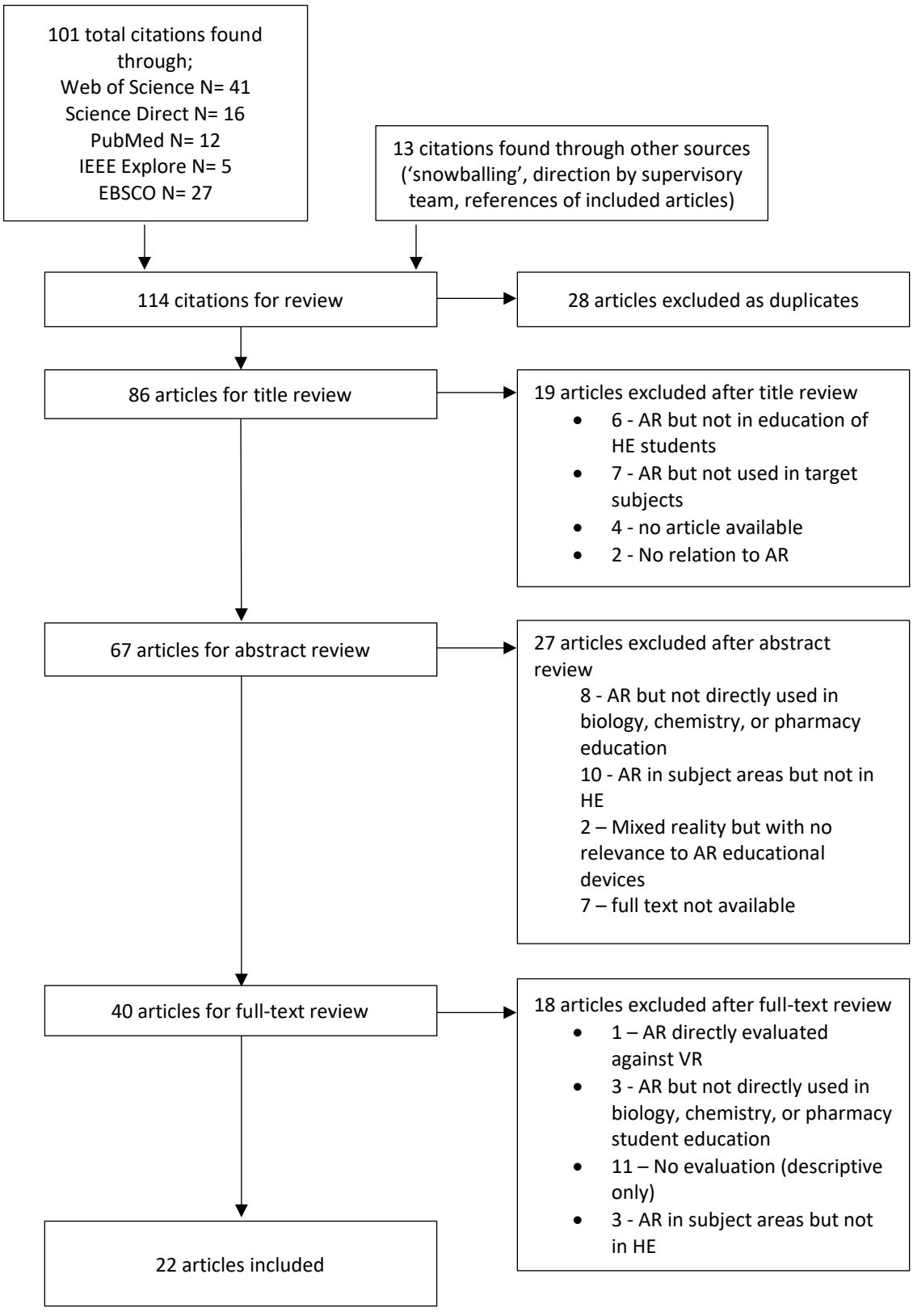


Figure 2.1 represents the screening process recommended by the PRISMA guidance (Page *et al.*, 2021a). A total of 22 articles were deemed appropriate for the narrative synthesis.

2.4.5 Data extraction

All 22 included articles were reviewed following the study selection process to formulate the preliminary synthesis. The extracted data presented in table 2.3 details the authors, year of publication, country of study, type of AR system used, participant characteristics (number, type of institution and subject), study design, data collection tools, and the outcome measures. The limitations and quality assessments of studies included in this review, which includes the quality assessment of the measured outcomes and data collection tools, are detailed in section 2.6.

Thematic analysis of the 22 articles was carried out to complete the full review. Thematic analysis is a commonly used method to analyse qualitative data in primary research, but it can also be used to systematically identify the central, most influential and recurring themes or concepts across multiple studies (Popay *et al.*, 2006). Although generally used for qualitative data, it has been argued that it may be used in studies that also involve quantitative data or mixed methods studies – variable labels within a survey can be extracted as a theme in the same way conceptual themes are extracted from conventional qualitative research (Mays *et al.*, 2005). Braun and Clarke (2006) developed a six-phased framework for thematic analysis of data: familiarise oneself with the data, generate initial codes, search for themes, review themes, define and name themes, and produce a report (also explained in Chapter 5.8.3). This process and framework were followed to extract each article's central themes, resulting in the construction of the full review (sections 2.5.1 to 2.5.5) (Braun and Clarke, 2006).

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
Abdinejad *et al.*, (2021)	Canada	Mobile APP markerless AR system (self-contained)	69 chemistry students	Undergraduate chemistry students were split into two groups, control and experimental groups. All students were given a worksheet with questions based on bond angles, 3D visualisations, and drawing various conformations. The control group used physical ball-and-stick models to aid them when completing the worksheet. The experimental group were given the ARchemy learning tool. All students were then asked to evaluate their understanding of the concepts using their respective learning aids.	Ball and stick model vs AR educational tool Evaluative questionnaire - Self-evaluation of understanding using respective interventions	The ability to visualise 3D models was reported to be equal between model kits and the AR tool. The AR tool was reported to be quicker for students visualising the models, easier to use, and depicted 3D models more accurately than the molecular model kits. Students agreed that the ARchemy app improved their ability to understand and visualise concepts in chemistry. Students view the AR tool as a valuable instrument to improve their assessment grades. Students found the app exciting and are highly interested in implementing the tool in their course. The study reports that the AR tool helped students better understand and visualise chemistry course material. These were subjective statements, as students reported that their perceived understanding and visualisation improved with the AR tool. The evaluative questionnaire had been used in a prior study by the same researchers.
Aw *et al.*, (2020)	Singapore	Mobile APP AR system using 2D images/QR targets	87 organic chemistry students	Undergraduate chemistry students first completed a pre-intervention questionnaire that collected baseline information before receiving the NuPOV AR tool. The tool was designed to provide users with an interactive visual representation of nucleophilic chemical reactions. Then, after a period (not specified in the article), students	Pre- and post-intervention study – Evaluative survey Five-point Likert scale focused on self-efficacy, learning aptitude and interest in chemistry	This study aimed to create an AR educational tool that would supplement current educational methods concerning chemistry education. Just under half of participants felt more confident with their understanding of nucleophilic addition after using the AR tool. Two thirds of participants felt more confident in solving more complex problems in the subject area. The study also reported that the app did not raise interest levels in the course but enabled students to learn

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				completed a post-intervention questionnaire. Both questionnaires contained five-point Likert scales that gathered data on self-efficacy, learning aptitude, and interest in chemistry.		organic chemistry without additional help. Students reported that having the app would not give them added desire to study more difficult organic chemistry courses. The study did not specify how long the intervention period was or what students specifically did with the AR tool during this period. The questionnaires used in this study were not reported to have been validated
Behmke *et al.*, (2018)	USA	Mobile APP AR system using 2D images/QR targets	238 chemistry students	College chemistry students were involved in a ten-minute AR based activity across four different terms of their course. Students were split in to control and experimental group sessions. The control group's activity was a paper and pencil exercise, then ended with the tutor reviewing the correct answers. These students were also able to use model kits as an aid. The experimental group used the Asurasma AR app, which allowed students to view and manipulate 3D molecules and their drawings side by side. After the teaching sessions, students completed an assessment to confirm whether molecules were identical or not. The AR tool was not permitted during the assessment, but all	Non-AR teaching session vs AR teaching session Knowledge-based questions Evaluative questions included in assessment – Questions asked what type of device would best help their learning of stereochemistry and why	The study aimed to enhance student learning of stereochemistry through the use of AR. A non-significant increase in experimental groups tests scores was found. Researchers were not surprised as the AR session only lasted ten minutes. Nevertheless, the result suggested that AR did not negatively impact students learning. The number of questions in the test was not specified. Students in the experimental group preferred computer-based AR models over physical models. Students in the control group preferred physical models over computer-based models as they accurately portrayed physical models. AR was reported to be easier and faster to access compared to physical models. Students favouring physical models stated AR had a lack of physical interaction – however, given the opportunity, students did not use physical models to prepare for the assessment.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				students could use physical model kits.		The study recognised that in order for more definitive answers regarding its impact on student performance, more detailed studies would be required
Chang and Yu (2017)	Taiwan	Mobile APP AR system using 2D images/QR targets	120 bioscience students	College bioscience/biology students self-studied according to topics set by their tutors prior to the bio-experiment curriculum. The bio-experiment (AR) curriculum lasted for four weeks. Students use the AR APP to guide themselves through five learning topics, each with their study test. After this, students completed a Short Feedback Questionnaire. The survey consisted of a five-point agreement Likert scale assessing subjective responses to the learning experience	Evaluative questionnaire regarding use and perception of AR – Likert scale Interviews - the number of interviews not specified in the article	Researchers aimed to understand the learning efficiency and App interface function by students after using the AR tool in fundamental biological experiments. The survey used had been deemed to be an effective assessment tool to collect subjective responses to VR learning by previous studies. The authors reported a high degree of agreement with Likert scale statements relating to; enjoyment, success, control realism and computer feedback suggesting high interest and good experiences with interactive AR learning. Students reported they could self-study using the tool, helping them to memorise experimental procedures, structures, and functions. Reports of improved student learning outcomes and motivation; however, no tools were used to measure these aspects of learning.
Gan *et al.*, (2018)	USA	Tablet APP AR system using 2D images/QR targets	10 chemistry and biology students	College biology and chemistry students participated in a small laboratory exercise. They were required to answer the first three questionnaire questions before starting the AR exercise. Following the exercise, they	Pre- and post-evaluative questionnaire format- Pre: Four Short answer MCQ Post: Three Likert scale questions (four-point scales)	The study claimed that the AR system could provide the opportunity for collaborative participation and discussions. This was anecdotally claimed as the study reported that the AR demonstration could be viewed from many viewing positions.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				completed the remaining three questions. The AR exercise demonstrated oxygen production from various hydrogen peroxide volumes. Results from the experiment were used to develop a graph on which simulated and actual volumes of oxygen were plotted against quantities of hydrogen peroxide		Although students were aware of the hazardous nature of hydrogen peroxide, bleach, and the flammable properties of pure oxygen, they were still apprehensive about handling the chemicals. Students agreed that the AR exercise was a good way to prepare before handling oxidizing reagents and combustible gases. Students also agreed that the AR tool could help improve their chemistry understanding. 100% of students either agreed or strongly agreed to being confident in using modern communication devices and electronic tools for learning. The questionnaire used in this study was short, with 7 questions total. The last three contribute to the AR tool's effectiveness. The study does not indicate if the questionnaire tool was validated
Habig, (2020)	Germany	Tablet APP AR system using 2D images/QR codes as targets	31 chemistry students	Undergraduate chemistry students were invited to complete a series of 20 MCQs. Half of the questions displayed 2D ball and stick representations, whereas the other half required students to use 3D AR models to answer. Students also completed a Purdue Visualisation of rotation test to gain insight into students' mental rotation ability. Additionally, students were asked to complete an evaluative questionnaire	Knowledge-based test – 20 MCQs on stereochemistry Purdue visualisation of rotation test (shortened version) Evaluative questionnaire – four-point Likert type scale on experience using the tool (11 items)	The combined average knowledge-based tests for all students was 6.63/14. No significant difference was found between the mean scores of 2D and 3D AR questions. AR was shown to be more effective for males rather than the initial assumption of compensating for reduced spatial abilities in females. Males scored significantly higher on AR questions than females ($p=0.011$). Students report seeing the potential benefit of AR and deemed it to be a meaningful supplement for 2D visualisation. They also reported high levels of interest and enjoyment while learning with AR models

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
Hou and Lin, (2017)	Taiwan	Mobile and tablet APP using 2D images/QR codes as targets	52 chemistry students	College chemistry students were divided into groups of four or five for a game-based learning session. Students were asked to complete a pre-knowledge-based test before using the AR tool in the game-based session. After the session, participants completed a post knowledge-based test and an evaluative questionnaire that measured flow, technology acceptance, perceived usefulness, and perceived ease of use.	Pre- and post-intervention tests – Knowledge-based Evaluative questionnaire 5-pont Likert scale – Flow antecedent and flow experience Technology acceptance scale	Two-part intervention tool (AR stage and virtual lab stage) The results revealed a statistically significant increase in understanding of chemistry items, laboratory security and the making of oxygen experiments. The mean rating of flow and technology acceptance indicated high acceptance. The mean perceived ease of use and usefulness suggested that students found the learning tool easy to use and valuable to their education.
Keller *et al.*, (2021)	Germany	Tablet APP AR system using 2D images/QR targets	61 students at the pre-test 41 students 27 phase 2 21 phase 3	Undergraduate chemistry students underwent a multistage study where they first completed a pre-test for content knowledge, metal rotation abilities and demographic data before being split into control (non-AR) and experimental AR group. Both groups then underwent a series of exercises and post-tests across four months. Each post-test collected content knowledge from the exercises just before the perceived cognitive load during those exercises and App useability for those in the experimental group.	Learning materials group vs AR and learning materials group Four-phased pre- and post-test format – Cognitive load evaluative questionnaire Useability questionnaire (SUS)	This study aimed to explore if students experience lower cognitive loads when using AR based learning tools compared to control groups. At each of the three post-test stages, students using the AR app reported lower intrinsic and extraneous cognitive loads than students using only learning materials (non-significant increase). Germane cognitive loads were almost identical except for when the exercises involved pericyclic reactions, where cognitive load in the AR students was higher than in the non-AR groups. Authors found that the AR app had high useability at each phase of the study. The study's results appropriately indicate that the intrinsic and extrinsic cognitive load of students studying stereochemistry, carbonyl-chemistry,

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
						and pericyclic reaction is reduced with AR compared to a reference group. They also appropriately reported that the AR tool had good useability.
Macariu *et al.*, (2020)	Romania	Mobile APP AR system using 2D images/words/QR codes as targets	200 students 70 professors	College chemistry students completed a useability task with the AR tool before conducting a short interview and a post-test questionnaire - The study did not report the nature of the AR task	Useability test –Short interview (number of interviews not reported), Evaluative survey questionnaire (QUIS) and task	Students successfully completed the task after observing someone else do the task. Participants became competitive as they transferred from one task to the next with ease. Participants rated their experience of AR as pleasant (9.7), with high levels of interactivity between users. Authors noted that visibly participants stess levels were reduced. Professors solved the task with notable ease, and rated their experience of the AR tool, functionality of the AR tool favourably. The study did not report specific questions from the QUIS questionnaire or the options for response, so it is difficult to judge what the average scores mean. The study claimed that students retained new information more easily after using AR; however, they did not specifically research this area or report comments from students alluding to this
Núñez *et al.*, (2008)	Spain	Computer AR system using 2D images/QR targets	15 inorganic chemistry students	Undergraduate chemistry students were involved in teaching sessions where the AR tool displayed 3D models of chemical structures. After the teaching session, students completed a questionnaire to gather their opinion on the AR tool.	Evaluative questionnaire	The study aimed to improve students' understanding of materials structure using AR and to provide tutors with a tool to help explain structures requiring good 3D spatial intuition. Students generally considered the AR tool to be helpful in understanding crystalline structures and consider AR to be powerful in helping participants understand the 3D arrangement of structures. Participants noted the ability to

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
						analyse, manipulate and interact with 3D models as a key advantage, there were further comments by participants reporting that the AR tool was valuable in improving visual and spatial skills. The study did not share the specific questions used in the survey. However, the study reports that students enjoyed the tool and learnt more inorganic chemistry with its use; however, this was not explicitly measured but may have been self-reported by participants.
Ovens *et al.*, (2020)	Australia	Mobile APP markerless AR system (self-contained)	42 students	Undergraduate chemistry students were involved in four laboratory sessions within their course. The availability to download and use the AR tool was made to students before the first session. After the fourth and final laboratory session, students were invited to complete an evaluative questionnaire based on the use and the intended use of the AR tool	Evaluative questionnaire – Use of intervention tool	This study served as a pilot that investigated the use of the AR tool among students Over half of study participants used the AR tool after the conclusion of the laboratory session. Just under half of study participants used the AR tool before or during the session. 48% of students used the AR application as part of their revision and exam preparation – whereas 67% of students intended to use the AR tool for exam prep come the end of the semester. The study reported that results indicate that the AR tool could make a good reflective and revision tool.
Reeves *et al.*, (2021)	UK	Tablet APP AR system using 2D images/QR codes as targets	20 biochemists	Undergraduate biochemistry students were split into two groups, where group one completed a knowledge-based test before participating in an AR educational session. Group two	Non-AR teaching session vs AR teaching session vs non-specialist participants (No teaching and no AR) completed a	Authors found that students involved in the AR session had a higher mean knowledge-based test scores than students involved in non-AR teaching session (non-statistically significantly).

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				participated in the AR session before completing the knowledge-based test. The teaching session required students to use tablets to scan targets in different room areas to generate AR models onscreen. Following this, both groups of students completed a questionnaire. A control group who did not study biochemistry also completed the knowledge-based test to evaluate 'guessability'.	test to evaluate 'guessability' Knowledge-based test – 13 MCQs Evaluative questionnaire – three, five-point Likert scale questions	A large proportion of students found that the AR teaching session was more engaging than lectures alone and helped their understanding of material. The authors found that participants would want to use AR in classes in the future. Sentiment analysis showed that students had an overall positive sentiment in their thoughts on the use of AR with terms such as "easier", "interactive", "Understanding", and "see" appearing regularly
Rodríguez *et al.*, (2021)	Switzerland	Website (computer) AR using both 2D images/QR codes as targets and markerless functions	17 tutors 99 students	Undergraduate and College participants of this study were invited to use the online AR platform to aid their chemistry and biochemistry education. Data on their use of the website was automatically collected. Additionally, some website users completed optional surveys, contributing to the evaluation.	Online evaluative questionnaire – Educators' perception of pedagogical impact	The study explained the difficulty of measuring the pedagogical impact of the AR tool as students were at home (COVID-19 protocol) and the tool was a freely accessible. Therefore, comparing the AR group to a control group was almost impossible. They instead opted to rely on the pedagogical observation of tutors. Educators perceived students to be interested in the web AR app. 82% of educators perceived the AR website helped improve their students' understanding. Students reported similar utility of the site as their tutors – 83% reported that the AR site helped improve their understanding. App released during COVID and saw high usage (55% of students stated to have used the tool only at home).

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
Safadel and White (2019)	USA	Mobile APP AR system using 2D images/QR targets	60 molecular biology students	Undergraduate biology students were split into control and experimental groups. The control groups used 2D interactive elements relating to DNA structure, whereas the experimental group used 3D AR models based on DNA structure. All students completed an activity where they had to sort components of molecular models	2D Computer environment vs 3D augmented reality application Evaluative survey – Satisfaction, useability of features, perception, and apprehension	The study's primary aim was to investigate the impact of AR on students' satisfaction when studying biology/biochemistry. Overall, there was a positive response concerning user satisfaction levels when using AR compared to 2D. Positive responses to the useability and perception towards the AR tool, as well as low levels of apprehension when using the AR tool. Questions related to all four elements of the evaluative survey had high significance when a Chi-square goodness of fit test was performed ($p<0.01$).
Salem *et al.*, (2020)	Australia	Tablets APP AR system using 2D images/QR codes as targets	33 clinical pharmacotherapy students	Undergraduate pharmacy students were introduced to students during a classrooms exercise and shown how to use the tool. They were then involved in an educational case study relating to an oral contraceptive drug that incorporated the HP Reveal AR tool. Upon completing the case study, participants were asked to complete a questionnaire on the AR learning tool's ease of use and acceptability.	Evaluative questionnaire –Five-point Liker scale to measure satisfaction and preference for AR learning module	This study served as a pilot study for the AR intervention, and it aimed to develop and assess the useability and acceptability of a student-centred AR learning module. The vast majority of students reported that the AR educational tool provided them with motivation to learn, improved their perceived knowledge and successfully presented material in a way that aids learning. The authors also found students agreed that AR was a useful resource and would not serve as a distraction to their learning.
Sanii,(2020)	USA	Mobile web-based AR system using 2D	23 students – classroom study	Undergraduate chemistry students used the AR tool in the classroom to view the hydrogen bonding of DNA molecules.	Evaluative questionnaire	The classroom study, student surveys and laboratory study all revealed that the majority of participants reported the AR tool aided their visualisation of DNA molecules and base pairs.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
		images/QR targets	32 students – student survey 32 students – laboratory study	Following this, they were invited to complete an evaluative questionnaire. In the laboratory session, students created and manipulated a fictitious molecule in PyMol, and viewed other molecules from a protein database before they generated their AR files.		Furthermore, participants reported better understanding of the material. A small proportion of users reported that AR was no more useful that drawings on the overhead projectors. There were a very small proportion of participants across the three different studies who report that they felt the AR tool was not helpful or that their time could be best spent on another modality of learning. The surveys used in the study were not reported, so the style and phrasing of questions could not be determined if they were validated.
Schmid *et al.*, (2020)	Germany	Mobile APP-based AR system using 2D Images/QR codes as targets	13 Inorganic chemistry students	Undergraduate chemistry students were given access to the AR tool during and after educational lectures. After this, students were invited to complete an evaluative questionnaire	Evaluative questionnaire – five-point Likert scale question (nine questions)	Users reported that the AR tool positively influenced learning success, as students claimed to have enjoyed its use. Students also wished for the tool to be further integrated into their classes. The questionnaire used in this study had not been reported to be validated. It collected self-reported responses to Likert statements. The study claims the tool could help improve understanding of the material; however, the results indicate it could improve students perceived understanding as no knowledge-based tests were carried out.
Schneider *et al.*, (2020)	Australia	Web Tablet APP AR system using 2D images/QR targets in magicbook	25 students	Undergraduate pharmacy students were invited to complete a demographic questionnaire and pre-knowledge-based test to gather baseline data. Students were	Pre- and post-intervention study – Knowledge bases test on Naloxone supply in pharmacy, four MCQs	This pilot study aimed to develop an AR tool and investigate its effectiveness for learning about a drug molecule.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				then introduced to the AR educational tool as they worked through an educational module. Students worked through the AR module at their own pace. After completing the exercise, they completed a post-knowledge-based test which included the same questions as the pre-test. Lastly, students were asked to complete an evaluative questionnaire to collect opinions on useability and acceptability	and one short answer question Evaluative questionnaire Useability/acceptability survey – six, five-point Likert scale statements and two open-ended questions	The authors reported a statistically significant increase knowledge-based tests after the use of AR the The AR tool was found to have a high user acceptability score. Participants reported the educational tool helped the acquisition and consolidation of knowledge, they reported positive emotional responses, ease of use, and suggestions to further improve the tool. The questionnaires used in this study had not been validated; however, this study was considered a pilot. The study did recognise that the pre- and post-questions were identical; nevertheless, results showed that more students answered the post-test question correctly after using the tool. The authors noted that further work is required to gain a proper understanding of the tool's acceptability and useability.
Smith and Friel, (2021)	USA	Mobile APP markerless AR system (self-contained)	Phase 1 – 42 Phase 2 – 101 Phase 3 – 36 pharmacy students	Undergraduate pharmacy students in phase one were involved in a teaching session on drug molecules using 2D images before receiving the AR tool. As a result, students could view and manipulate the same drug molecules in the model view. Students then went on to complete an evaluative questionnaire.	Phased development of AR educational tool Evaluative survey – ease of use and perceived changes in understanding Knowledge-based assessment – course exam performance	Phase one – 3D model on a solid background (Model view) Phase two – 3D model on a solid background (Model view) Phase three – genuine AR system true AR view) The majority of participants in phase 1 and 2 of the study found the AR models easy to use. This proportion was slightly less in phase 3. Over half of the participants reported the true AR tool helped their understanding of concepts and to prepare for upcoming teaching sessions. The use

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				In phase two, AR models of drug models were provided to students before a lecture so they could be used during the session. These models included improvements suggested in phase one. Students were then asked to complete the same survey as they did in phase one. Phase three involved a lecture session on the mechanism of action of drug molecules before working in pairs to view AR drug molecules. Students were again asked to complete an evaluative questionnaire.		of AR helped learners improve the rate of correctly answering exam questions from 43% to 59% after the introduction of the AR teaching session; however, the study claimed the improvement was anecdotal.
Sung *et al.*, (2020)	USA	Mobile APP AR system using 2D images/QR targets	27 biochemistry students	Undergraduate chemistry students worked in groups of three and four for 50 minutes on a worksheet task which included questions on macromolecules. Following this, students used the AR BiochemAR tool to view 3D models of ion channels. Students were then asked to complete follow-up questions.	Pre- and post-self-efficacy evaluative questionnaire – Likert scales Pre- and post-intervention worksheet task	The study aimed to develop a simple, easy to use AR based teaching tool; the assessment of the intervention tool was focused on its useability. Participants reported that the AR tool helped them to visualise structures and aided their spatial understanding of ion channels. They also reported AR helped to verify and clarify their understanding of concepts. Data collection tools were not validated, but included reverse scored statements to improve validity. The study reported improving students' spatial awareness in their understanding of the material; however, the study suggests it improves students' self-reported level of spatial awareness.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
Wong *et al.*, (2020)	Hong Kong	Mobile APP AR system using 2D images/QR codes as targets	218 general and organic chemistry students	College chemistry students were involved in a teaching session where a teacher-designed AR learning tool was incorporated to provide a 3D representation of chemical structures. Students then went on to complete a group worksheet/group mini-project to test their knowledge. Questionnaires were administered after the teaching sessions to evaluate the effectiveness of learning chemistry with the AR tool. Students also completed a pre- and post-test knowledge-based quiz	Evaluative questionnaire – 5-point Likert scale questions Pre- and Post-intervention knowledge test Group mini-project - Measure active learning	Students reported a perceived improvement in their understanding of abstract concepts. Participants also reported that the tool was an effective educational device as it reportedly enhanced student-tutor interaction, and improved their ability to visualise, name and draw compounds.
Wozniak *et al.*, (2020)	Poland	Tablet APP AR system using 2D images/QR targets	2 chemistry students (prototype intervention study)	Undergraduate chemistry students were involved in completing two laboratory tasks. Task A, a regular experimental exercise from analytical chemistry, and Task B, an abstract task of mixing and measuring liquids. Task A was limited to 50 minutes and supervised by a lab assistant, whereas task B was unsupervised with no time limit. Task B was supported by the AR tool. Participants completed a system	Non-AR laboratory task vs AR laboratory task Observation – video recorded of participants as they completed the tasks Time taken to complete the task was recorded Evaluative questionnaire - System useability scale (sus)	A preliminary study aimed to evaluate the prototype ARchemist tool by measuring participants' time taken to complete a task with and with the assistance of the AR tool. Students completed laboratory tasks in shorter time when using the AR tool. Participants found the tool advantageous and convenient to use. They gained confidence using the AR tool and reported fewer procedural errors. They found the use of tablets was unsuitable for specific settings due to its size.

Author (Year)	Country	Type of AR System	Participants	Setting and Subject/topic	Data Collection format and tool/s	Outcomes
				useability scale (SUS) survey on the completion of the tasks, followed by an interview	Interviews with two participants	The study recognises that a full-scale investigation would be needed in order to understand the tool's total impact on the laboratory process

Table 2.3 displays each of the 22 studies identified from the literature search and deemed eligible for this review using the inclusion and exclusion criteria.

2.5 Narrative Synthesis Findings

2.5.1 Overview of Findings

After reviewing the literature search results, 22 evaluative articles met the inclusion and exclusion criteria evaluating AR educational tools with or without comparative control measures (table 2.3). In total, four different formats of AR systems were described in the literature (table 2.4). The AR systems of two articles were identified from figures and diagrams included in the published article due to poor intext descriptions. Image-based systems were the most popular of the AR systems developed and evaluated. These systems utilise unique 2D images or QR codes that trigger the system to display the respective programmed 3D models and animations when scanned. These systems are described in the table below (table 2.4) as a “self-contained app”, referring to its ability to function without GPS or internet connections (all programmed content is contained within the app). Markerless and web-based (required targets) AR systems were the next most popular, identified as being evaluated in three studies each. Markerless systems are also described in table 2.4 as “self-contained apps”, again referring to the ability of the app not to require GPS or an internet connection to function. These systems have 3D models and animations programmed within the app, and the user selects the 3D elements from a list within a menu. Web-based systems require a connection to the internet to display the programmed 3D models or animations. All web-based AR systems included in this review required the recognition of physical 2D images or QR codes that would trigger the systems to produce the 3D elements sourced from the internet. In addition to target image/QR code recognition, one web-based AR system could also display 3D models without the recognition of targets, resulting in a hybrid web-based marker/markerless system and is therefore categorised into both groups in the table below.

	Category	Number of studies
Type of AR system*	Image/QR code target (self-contained app)	16
	Markerless (self-contained app)	3
	Web-based (requires targets)	3
	Web-based markerless	1
Devices used	Mobile	13
	Tablet	7
	Computer	2
AR Software	A-Frame	1
	ARKit	2
	ARToolKit	1
	Augment	2
	HP Reveal (formerly Aurasma)	3
	MERGE	1
	OpenCV/ArUCo	1
	Sketchfab	1
	Unity	2
	Vuforia	5
	Unknown	2
	Zapworks	1
Level of education*	College	7
	Undergraduate	16
Subject*	Biology	3
	Chemistry	17
	Pharmacy	3

Table 2.4 details the following features from each of the 22 articles included in this literature review – the type of AR system evaluated, the devices and software used in the system, the level of education and the educational subject. *Categories where an AR tool fulfils more than one sub-category (Rodríguez (2021) in both college and undergraduate, web-based markerless and web-based (requires targets) categories; Gan *et al.*, (2018) in both biology and chemistry subject categories)

Thirteen of the AR systems described in each article were primarily developed for mobile phones, seven were designed for use on tablets, and the remaining two were developed for desktop computers or laptops. It should be mentioned that some of the AR applications described may be utilised on both smartphones and tablets but are categorised in table 2.4 according to the devices used in the presented studies (Gan *et al.*, 2019; Hou and Lin, 2017; Keller *et al.*, 2021; Reeves *et al.*, 2021). Table 2.4 also displays the wide range of software developers use to create AR educational tools, the most common being Vuforia, followed by

HP reveal (Aurasma). Almost 70% of the included studies involved participants enrolled on undergraduate university courses, and the remaining studies were conducted with participants from colleges. One study included both undergraduate and sixth form equivalent students and therefore was categorised under both in table 2.4. Studies were carried out in a variety of different countries across the world – e.g., North America to Hong Kong, Germany to Australia. However, only one study was conducted in the UK. This observation demonstrated the broad application of AR's use globally and indicated a potential gap in research related to AR in education within the UK. As studies had taken place in countries outside of the UK, the participants' level of education were cross-referenced to ensure they met the inclusion and exclusion criteria - level three to level seven UK qualifications or equivalent (Department for Education, 2022). It was clear that chemistry topics such as organic and inorganic chemistry were most frequently incorporated into AR educational systems (17 articles), whereas biology and pharmacy educational AR systems were the focus of only three studies each. One study involved biology and chemistry students and is therefore represented in the biology and chemistry sub-categories in table 2.4.

The use of comparative studies was employed in six of the 22 articles, comparing AR educational tools to either more conventional tools or control groups (i.e., AR vs no AR, AR plus X conventional tool vs X conventional tool). Of these six studies, two compared AR educational tools to other interactive teaching interventions (physical ball and stick models and 2D computer environment), and four employed more conventional control groups (non-AR teaching sessions or classroom activities that involved 2D drawings and diagrams).

The remaining 16 articles evaluated educational AR tools without the comparison of an additional type of learning tool.

The included studies were also analysed to identify different data collection tools used to evaluate the effects of AR in education. Some form of an evaluative questionnaire (22 studies) was used in every article and assessed participants' attitudes towards the intervention and their learning. These attitudes comprised self-efficacy, useability, acceptance, satisfaction, motivation, and perceived understanding of concepts. Knowledge-based assessments were the following most frequently used data collection tool and assessed changes in knowledge that may be attributed to the AR tools (seven studies). Other data collection tools that were used in reviewed articles were interviews (three studies), observations (one study) and the completion of a task/project (three studies). Of the 22 studies, 10 utilised more than one data collection tool. In addition, seven studies used pre- and post-intervention period formats, enabling researchers to evaluate changes in perspectives, knowledge and or performance that can be attributed to AR tools.

All 22 articles were thematically analysed, which resulted in the emergence of the following themes that will be further explored in sections 2.5.2 to 2.5.5

- AR's effect on knowledge development.
- AR's effect on skill development.
- Users' satisfaction and accessibility to AR.
- Design of AR educational tools.

2.5.2 AR's effect on knowledge development

Thematic analysis of the reviewed literature indicated that AR could improve students' knowledge and understanding of sixth form and undergraduate biology, chemistry, and pharmacy material. Five studies investigated and documented objective changes in knowledge attributed to using an AR educational tool, which showed improvements in understanding related educational content. The significance of these results, however, varied, with significant improvements found in two studies (Hou and Lin, 2017; Schneider *et al.*, 2020) and non-significant increases seen in the other three articles (Behmke *et al.*, 2018; Habig, 2020; Reeves *et al.*, 2021). The studies by Hou and Lin (2017)) and Schneider *et al.*, (2020) utilised pre- and post-knowledge-based quizzes to measure changes in knowledge associated with the AR tools. In contrast, Behmke *et al.*, (2018), Habig (2020), and Reeves *et al.*, (2021) compared the quiz scores of participants who were involved in non-AR activities to the scores of participants engaged in AR activities. Although Habig, (2020) did not find significance across all participants, they did report statistically significant improvements in male participants' scores after using the AR educational tool. This finding surprised the authors as they hypothesised that the device would aid female users more than male users due to differences in visuospatial abilities between the sexes. Concerning the relationship between the length of the study and the size of improvements, both studies that documented statistical significance were conducted after a single AR teaching session/single use of the educational tool (Hou and Lin, 2017; Schneider *et al.*, 2020). Of the studies that did not find statistically significant differences in knowledge improvement, only one was a longitudinal study carried out over an entire academic year (Behmke *et al.*, 2018); the others evaluated the immediate effects of the AR tool after exposure to the AR tool on an individual occasion (Habig, 2020; Reeves *et al.*, 2021). This observation suggests a need for

further longitudinal studies to evaluate AR's effects on students' academic knowledge objectively. All the AR educational tools evaluated in relation to changes in knowledge were images-based AR tools.

In addition to objective improvements in knowledge and understanding, eight studies also reported that participants perceived to have improved knowledge and understanding of related subject matter after the use of the AR educational tool (Chang and Yu, 2017; Macariu *et al.*, 2020; Rodriguez *et al.*, 2021; Salem *et al.*, 2020; Sari *et al.*, 2021; Smith and Friel, 2021; Sung *et al.*, 2020; Wong *et al.*, 2020). The perceived improvements in knowledge and understanding were most commonly recorded using Likert scales. Reported claims of improved material retention were over four weeks in Chang and Yu's (2017) study and 15 months in Smith and Friel's (2021) study. The other articles reported a perceived improvement after a single AR teaching session. Findings from one particular study reported from the perspective of tutors and detailed a perceived improvement in the ability to reach academic learning outcomes using AR (Rodriguez *et al.*, 2021). Sung *et al.*, (2020) reported a statistically significant increase in the perceived knowledge of university biochemistry students (self-efficacy) after using the AR educational tool compared to before its introduction. Although the differences were statistically significant, the findings related to the students' perceived improvements and not the objective improvement in knowledge. The authors reported that the tool helped to verify and clarify students understanding of academic material based on the comments and observations of participants.

The educational AR technology had also been discussed concerning its ability to facilitate learning and its role in pedagogy that may have contributed to the improvements in

knowledge reported above. AR educational tools have been described as capable instruments to support current and well-established pedagogies (Aw *et al.*, 2020; Gan *et al.*, 2019; Macariu *et al.*, 2020; Ovens *et al.*, 2020; Safadel and White, 2019; Sari *et al.*, 2021; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Sung *et al.*, 2020; Wong *et al.*, 2020). Ovens *et al.*, (2020) described how their AR tool was a useful application for students to reflect and revise in preparation for, as well as use during laboratory experiments, while others highlighted AR's ability to facilitate self-directed and teacher-students active learning environments (Chang and Yu, 2017; Sari *et al.*, 2021; Smith and Friel, 2021). AR has also been reported to be capable of supporting collaborative and inclusive educational environments between learners (Macariu *et al.*, 2020; Sari *et al.*, 2021; Schneider *et al.*, 2020; Smith and Friel, 2021), as well as supporting learners during their self-directed studies (Aw *et al.*, 2020; Schmid *et al.*, 2020). An improved learning experience was reported by both Keller *et al.*, (2021) and Núñez *et al.*, (2008). The former attested that the improved learning experience and high reported useability of their AR tool helped reduce students' intrinsic and extraneous cognitive loads. Not only was it suggested to be able to support current methods of learning, but it had also been recommended that AR educational tools could champion less obvious and more innovative instructional forms of education, such as new methods of student-centred, game-based, or experiential learning (Chang and Yu, 2017; Safadel and White, 2019; Salem *et al.*, 2020; Sari *et al.*, 2021).

Four articles included in this review reported that through 3D visualisation of molecules, AR educational tools enabled users to understand concepts and phenomena subjectively better, mainly models educators and authors considered to be complex. The added depth perception of molecules to understand spacing (Aw *et al.*, 2020), spatial awareness of ion

channels (Sung *et al.*, 2020), reduced cognitive load caused by improving the visualisation process of mentally rotating structures (Keller *et al.*, 2021), and additional viewing angles (Schmid *et al.*, 2020) all reported to have contributed to a perceived improvement in understanding. The findings from the Abdinejad *et al.*, (2021) study suggested that the perceived improvement in understanding concepts and phenomena stemmed from the ability to visualise 3D representations of unobservable phenomena.

Additional reports by study authors concerning AR's effect on learning suggested improvements to a learner's attitude towards learning (Chang and Yu, 2017; Salem *et al.*, 2020; Sari *et al.*, 2021). High levels of enjoyment and interest attributed to the use of AR were reported in Chang and Yu's (2017) study, whereas a perceived improved learning experience with greater perceived motivation was reported by Salem *et al.*, (2020). Salem *et al.*, (2020) also found that participants enjoyed the interactive elements of AR and that it contributed to users expressing greater motivation towards learning. Nevertheless, comments that linked higher levels of enjoyment to improved motivation were not reported frequently enough to be considered a theme but were made speculatively. These articles then stated that further investigation was needed to identify what elements of AR caused improvements in reported attitudes and motivation towards learning.

2.5.3 AR's effect on skill

Not only did the literature reveal AR's effects on the learning process and understanding of educational material, but six studies also reported enhancing the skills of chemistry, biology, and pharmacy students. Of these six studies, four were comparative (M Abdinejad *et al.*, 2021; Safadel and White, 2019; Sung *et al.*, 2020; Wozniak *et al.*, 2020) and two were

evaluative (no control group) (Núñez *et al.*, 2008; Sanii, 2020). These improvements were reported to affect students' laboratory procedure skills (Wozniak *et al.*, 2020), visualisation skills (M Abdinejad *et al.*, 2021; Núñez *et al.*, 2008; Safadel and White, 2019; Sanii, 2020; Sung *et al.*, 2020) and spatial abilities (Sung *et al.*, 2020).

Most frequently mentioned was AR's ability to display 3D visual representations that contributed to an improvement in the user's ability to visualise structures and models (M Abdinejad *et al.*, 2021; Núñez *et al.*, 2008; Safadel and White, 2019; Sanii, 2020; Sung *et al.*, 2020). As mentioned in section 2.5.2, AR was suggested to improve a user's understanding of chemistry, biology and pharmacy material due to its ability to present visual representations of phenomena and concepts. The ability to manipulate these 3D models provided learners with new viewing angles and, thus, helped to build more complete visual representations in the user's mind (M Abdinejad *et al.*, 2021; Sanii, 2020; Sung *et al.*, 2020). Through their improved visualisation skills, researchers reported that participants exhibited improved perceived spatial intuition (Núñez *et al.*, 2008). This study, however, did not objectively investigate improvements in participants' spatial intuition but reported the perceived improvements. In an evaluative questionnaire, 40% of participants said the main advantage of the AR tool was the ability to view 3D models from a variety of different angles, and an additional 20% commented that this was perceived to have improved their visual and spatial skills (Núñez *et al.*, 2008). A perceived improvement in spatial and visualisation skills has been reported to have positively affected learners' self-efficiency. Therefore, developing these skills could help students' performance in chemistry and biology-related subjects (Safadel and White, 2019). Most studies (21/22) reported a perceived improvement or enhancement in visualisation abilities as an immediate effect of

using AR educational tools. Some of these comments were received after a single encounter in an AR teaching session (M Abdinejad *et al.*, 2021; Núñez *et al.*, 2008; Safadel and White, 2019; Sanii, 2020). The only article to report these improvements after prolonged use of AR was by Sung *et al.*, (2020). Comments surrounding the development of skills were reported less frequently compared to the user satisfaction comments; a potential reason for this may be because the articles were relatively early evaluative studies conducted as a 'proof of concept' investigation that would require further exploration to determine the magnitude and more subtle effects of AR's use.

When used in the context of laboratory experiments, Wozniak *et al.*, (2020) found students completed laboratory tasks in less time with the use of their AR tool and found the tool useful in post-experiment analysis and report preparation – the ARchemist tool detailed 3D representation of each step of a laboratory procedure and therefore was a source to refer back to for analysing methods and completing laboratory reports. AR was found to improve students' perceived laboratory skills and perceived confidence when handling harmful chemical reagents, ultimately reducing chemophobia. It afforded users access to and build familiarity with chemicals and laboratory equipment in a safe, controlled environment leading to refined laboratory practical skills (Gan *et al.*, 2018).

In relation to how researchers measured the skills mentioned, Wozniak *et al.*, (2020) appropriately measured the time taken to complete a laboratory experiment with and without using the AR educational tool to determine if the intervention helped improve the practical skills of the learner. However, the two tasks completed were different from one another. Therefore one task could inherently take longer to complete than the other.

Although participants completed the two tasks in reverse order to each other, the study did not report that the two tasks were equivalent in difficulty or completion time (a maximum time per task was set at 50 minutes). Concerning learners' visualisation and spatial abilities, several studies reported subjective improvements via questionnaires (M Abdinejad *et al.*, 2021; Núñez *et al.*, 2008; Sanii, 2020; Sung *et al.*, 2020). To objectively measure changes in an individual's visualisation and spatial abilities, learners would need to be subjected to tests designed to measure such skills, such as the Pardue Visualisation of rotation test used in Habig's (2020) study. This test measures the mental rotation abilities of participants and found no significant differences between students who used 2D or 3D AR models.

2.5.4 Users' satisfaction and student accessibility to AR

Almost a third of the articles (15/22) included in this review focused on the user experience of a newly developed educational AR tool and, as such, explored participants' perspectives primarily through Likert scales and Likert type statements. The literature was perceived to overall be favourable towards AR and its use in educational settings, with reports of higher levels of enjoyment, interest and excitement, user engagement and more positive perspectives towards learning compared to learning with non-AR educational tools (Chang and Yu, 2017; Habig, 2020; Núñez *et al.*, 2008; Reeves *et al.*, 2021; Sanii, 2020; Sari *et al.*, 2021; Schmid *et al.*, 2020; Wong *et al.*, 2020). In addition, favourable comments were received from college and undergraduate chemistry and biochemistry students who used imaged-based AR systems - one study utilised a computer and camera specification, whereas the remaining six used either a smartphone or tablet device. These reports of favourable attitudes towards AR in education may suggest a bias in how the findings were presented, as all the studies were conducted by the same researchers or institutions that

developed the educational AR tools and would likely want to portray their tools positively light. The level of bias, however, was not reported or alluded to in any of the 22 articles, and no further comments were reported that detailed the AR tools had been reviewed by independent researchers. Hou and Lin's (2017) study reported that students enjoyed their experience using a mobile image-based educational AR tool and reported high degrees of flow between tasks and high levels of technology acceptance. Flow was described as the state of complete engagement in an activity and referred to the optimal experience where the goal-driven activity is the only thing that matters (Kiili, 2006). Although not mentioned in the article, the flow between AR tasks may have been improved as a result of the mobile format of the AR tool may have given users more physical freedom than a station computer-based arrangement.

Although not explored in all studies, findings from four studies explicitly explored the useability and user satisfaction of their respective tools and revealed the perceived ease and speed of use when employing AR educational tools in academic activities (M Abdinejad *et al.*, 2021; Behmke *et al.*, 2018; Rodriguez *et al.*, 2021; Safadel and White, 2019). Safadel and White (2019) found a statistically significant difference between students' satisfaction when carrying out 2D and AR activities. However, the authors did not report the difficulty of determining statistically significant differences of perceptions. Participants were also reported to believe that AR would have a high degree of acceptance should it be implemented on a much larger scale within higher education, also reported in two other studies (Safadel and White, 2019; Salem *et al.*, 2020; Smith and Friel, 2021). As mentioned before, studies recognised that these perceived comments required further investigation to understand these claims' significance in more detail. A significant proportion (calculated by

the respective authors of the studies) of first-time AR users reported AR systems to have "good' useability (Rodriguez *et al.*, 2021) and be "easily learnable" (Wozniak *et al.*, 2020). The useability of the AR system investigated by Keller *et al.*, (2021) was deemed a critical factor in reducing students' extraneous cognitive load as the two elements are closely tied to one another. On the three occasions where students rated the tool highly useable, they also reported having experienced lower levels of extraneous cognitive load. Smith and Friel (2021) found that AR technology can be easily implemented into educational exercises that take place before, during, or after teaching sessions to help reinforce students understanding of medicinal chemistry concepts. It should be mentioned that the demographic of participants may have also contributed to the reports of relative ease and speed of use. When age was reported, most participants were between 18 and 25 (Keller *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Wong *et al.*, 2020; Wozniak *et al.*, 2020). This age group of learners are considered digital natives with an affinity for smartphones and technology use in their education. Therefore, higher reported speed and use levels may be expected (Iqbal and Bhatti, 2020).

The ease and speed of use can be attributed to the components of the AR systems. The devices used in all the AR educational tools in this literature review (mobile phones, tablets, and computers) are widely accessible, so individuals may have had experience with the hardware prior to the studies. Schmid *et al.*, (2020) added that the high prevalence AR compatible devices might increase the likelihood of learners gaining access to such experiences and the associated benefits to their learning experiences. However, no studies reported data about participants having previously used AR in any capacity. To add to the notion of accessibility, the literature also reported on the relatively low financial cost of

producing complete educational AR experiences as 3D models and that AR software is widely accessible via online websites for free (M Abdinejad *et al.*, 2021; Gan *et al.*, 2018). Schneider *et al.*, (2020) explained that the current financial costs to develop and use educational AR tools are lower than they previously had been since most students now own mobile devices capable of supporting AR apps, further increasing their accessibility.

Accessibility can also be discussed in terms of access to learning material, Salem *et al.*, (2020) explained how undergraduate pharmacotherapy education requires students to have access to medicines beyond formal teaching sessions. Usually, this may occur through arranged clinical placements in practice (hospital, community and industrial pharmacy) to provide learners with the realistic medicine-handling experiences they would encounter once qualified. They went on to further highlight that AR models of actual medicine packets can afford students access to resources (medication used in dispensing classes) at a time that is convenient for them, extending the learning opportunity. In normal circumstances dispensing classes would take place in environments that simulate healthcare settings with actual medication. The AR models would then provide learners with an extended opportunity to view and handle 3D models of real medication outside of set classroom sessions. Chang and Yu (2017) shared a similar perspective: if AR is co-located with fundamental biology experimental textbooks, students can direct their studies without a restriction in time or space. The article by Wong *et al.*, (2020) highlighted the benefit of increasing accessibility to educational content, particularly during the COVID-19 pandemic. He explained how students are heavily dependent on electronic devices to seek and obtain information and entertainment and that AR, owing to its simplicity of use and accessibility,

could be broadly utilised not only for chemistry students to visualise compounds but also for chemistry tutors to develop new teaching materials to support distance learning.

2.5.5 Design issues related to AR Systems

Every article included in this review was an early evaluative study to evaluate newly developed AR educational systems. Four articles were disclosed as pilot studies involving AR, illustrating that research in this area is at an early stage(Ovens *et al.*, 2020; Salem *et al.*, 2020; Schneider *et al.*, 2020; Wozniak *et al.*, 2020). As mentioned in chapter 1.7, AR can be created using a number of different hardware devices. The majority of AR educational tools described in the included studies opted to employ tablet or smartphone devices (M Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Safadel and White, 2019; Salem *et al.*, 2020; Sanii, 2020; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Sung *et al.*, 2020; Wong *et al.*, 2020; Wozniak *et al.*, 2020) - the only other hardware device used was computers with auxiliary cameras connected (Núñez *et al.*, 2008; Rodriguez *et al.*, 2021). The favourability of mobile devices over stationary hardware like computers may have been due to affordances of portability, thus allowing the educational tool to provide learners with more freedom during its use. As detailed in section 2.5.2, the majority of AR educational tools described in included articles required the recognition of visual 2D images or QR codes – 16 of those 19 AR tools were self-contained, whereas the remaining three required an internet connection that would access the 3D models from an online cloud recognise the 2D target. The markerless AR systems were only reported to have been used in four articles, one of which could also register 2D targets to produce 3D models. Concerning the generation of the 3D

models (when reported), some authors chose to export structures from freely accessible online databases such as the Protein Data Bank, Pymol and PubChem databases (Habig, 2020; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Sanii, 2020). Conversely, others resorted to creating unique models and animations from scratch using platforms such as Blender and Octave (Sanii, 2020).

Aside from the positive findings and comments by participants explored in the previous sections, the authors' observations uncovered issues associated with the design of the AR tool. Although the number of observations reported was few and far between, they related to the tool's design. Two studies reported issues related to the type of device used in the AR system (Behmke *et al.*, 2018; Wozniak *et al.*, 2020). Wozniak *et al.*, (2020) found in their pilot study that a tablet was rather unsuitable to use when carrying out an experiment inside a fume cupboard. This comment suggests that the device's suitability to the task and its environment is an essential factor to consider when developing educational AR systems. Behmke *et al.*, (2018) also described their system as cumbersome, with a time-intensive process to generate new unique AR based molecules from scratch. As mentioned, other developers chose to import existing 3D models for online databases (e.g. Protein Data Bank and PubChem database) into their educational tool, thus significantly reducing the cost in time to create content (Habig, 2020; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Sanii, 2020). Formulating lectures and lesson plans is already time-intensive for educators, so creating new 3D models for an AR educational tool would further intensify this process. Moreover, Behmke *et al.*, (2018) further explained that due to a large number of models users may request, content creation could be a significant hurdle depending on how the models are produced.

Subsequent to those comments, authors noted that their systems lacked functions for tactile interactions with the 3D models other than increased viewpoints for observation. On-screen buttons and 'pinch to zoom' gestures were noted to possibly offer users greater forms of interactivity with the onscreen 3D content improving the user experience (Behmke *et al.*, 2018; Sanii, 2020).

2.6 Limitations and Quality Assessment of studies

In order to ensure a standard of quality within this review, the quality of each included study was assessed. Various methodologies were implemented in the included articles and, as such, would require a quality assessment tool with a high degree of versatility. Morrison *et al.*, (1999) developed a nine-point tool with such capabilities, specifically intended to appraise reports of educational interventions. The following factors were used to critique each of the 22 articles. Is/are there: a clear research question, a clear learning need, a clear educational context, a clear description of the intervention, an appropriate study design, appropriate methods, appropriate outcomes, any other explanation of the results, any explanation of unanticipated outcomes. The checklist criteria are subjective and rely upon the judgement of the review writer. Table 2.5 below documents the main criteria against which each article was critically assessed. There were a number of limitations which presented difficulties in assessing the quality, the most notable were the descriptions of participants, the design of the AR tool, the reliability/validity of data collection tools and the explanation of secondary or unexpected outcomes.

Paper	Clear question?	Clear learning need?	Clear description of educational context?	Clear description of Intervention?	Appropriate study design?	Appropriate Methods?	Appropriate outcome measures?	Other explanation of results?	Explanation of unanticipated outcomes?
Abdinejad *et al.*, (2021)	Yes	No	Yes	Yes	Yes	Yes	Partly – the survey had been used in a previous study by the same researchers	Yes	Yes
Aw *et al.*, (2020)	Yes	Yes	Yes	No	Yes	Yes	No	No	No
Behmke *et al.*, (2018)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Chang and Yu, (2017)	Yes	Yes	Yes	Partly - The nature of the AR tool is inferred from images	Yes	Yes	Partly – Used Short Feedback Questionnaire developed by Kizony to assess subjective responses to learning with VR	No	No
Gan *et al.*, (2018)	Yes	No	Yes	Yes	Yes	Yes	No	No	No

Paper	Clear question?	Clear learning need?	Clear description of educational context?	Clear description of Intervention?	Appropriate study design?	Appropriate Methods?	Appropriate outcome measures?	Other explanation of results?	Explanation of unanticipated outcomes?
Habig, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes – Cronbach alpha (MCQs =0.70)	Yes	Yes
Hou and Lin, (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes – Cronbach alpha (0.905) The usefulness scale was taken and adapted from another study	No	No
Keller *et al.*, (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes – Cronbach alpha	Yes	Yes
Macariu *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Partly – QUIS was used, but the tool was not disclosed in the study	No	No
Núñez *et al.*,(Núñez *et al.*, 2008)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Ovens *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No

Paper	Clear question?	Clear learning need?	Clear description of educational context?	Clear description of Intervention?	Appropriate study design?	Appropriate Methods?	Appropriate outcome measures?	Other explanation of results?	Explanation of unanticipated outcomes?
Rodríguez (2021)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Safadel and White (2019)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Salem *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes – Cronbach alpha (0.822)	Yes	Yes
Sanii (2020)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Schmid *et al.*, (2020)	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No
Schneider *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Smith and Friel (2021)	Yes	Yes	Yes	Partly - The nature of the AR tool is inferred from images	Yes	Yes	No	Yes	Yes
Sung *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Partly – The survey included reversely score statements to	No	Yes

Paper	Clear question?	Clear learning need?	Clear description of educational context?	Clear description of Intervention?	Appropriate study design?	Appropriate Methods?	Appropriate outcome measures?	Other explanation of results?	Explanation of unanticipated outcomes?
							increase the validity		
Reeves *et al.*, (2021)	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Wong *et al.*, (2020)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Wozniak *et al.*, (2020)	Yes	Yes – Conducted a preliminary study to understand the processes and issues of efficiency in the laboratory	Yes	Yes	Yes	Yes	No	Yes	Yes

Table 2.5 displays the quality assurance criteria for each of the 22 studies included in this literature review based on the checklist by Morrison *et al.*, (1999).

Although each article documented the participants in their respective studies, there were two main notable limitations. Firstly, six studies were reported to include less than 20 participants (Gan *et al.*, 2018; Núñez *et al.*, 2008; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Schmid *et al.*, 2020; Wozniak *et al.*, 2020). Of these studies, two were purely quantitative (Gan *et al.*, 2018; Schmid *et al.*, 2020), three employed both quantitative and qualitative methods (Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Wozniak *et al.*, 2020), but the last of the six studies did not report its data collection tool in enough detail to determine if a quantitively or qualitative approach was used (Núñez *et al.*, 2008). Low participant numbers in a quantitative study would result in a poor representation of the broader sample population and could reduce the reported findings' reliability. However, should the study report to be a pilot quantitative study, a low number of participants would be acceptable as the aim of that study would not necessarily be to provide generalisable findings but to ensure the appropriateness of the data collection tools and methods (Drennan, 2013a; Roopa and Rani, 2012; Schwarz, 1995). In qualitative studies, a low participant number may be sufficient to draw reliable conclusions as data saturation could occur early in the data collection process; however, no study reported to have reached data saturation regarding their qualitative findings. Secondly, although some studies reported large participants numbers (ranging from 87 to 238 participants) (Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Macariu *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020), only two out of the 22 studies recruited participants from more than one institution (Macariu *et al.*, 2020; Rodriguez *et al.*, 2021). This limitation also reduces the generalisability of the results, as not all students are the same as those involved in the studies. Recruiting participants from the same institution that developed the educational tool may also add a layer of participant bias. Participants may report that the tool had a more significant perceived

impact on the measured phenomena due to their association with the institution. It should also be noted that although most articles were primary studies evaluating AR educational tools, none reported having used power calculations to select appropriate sample sizes to report statistically significant results. This also included studies that reported statistical significance in their findings (Behmke *et al.*, 2018; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Reeves *et al.*, 2021; Safadel and White, 2019; Schneider *et al.*, 2020; Sung *et al.*, 2020). Power is essential when calculating appropriate sample sizes and helps to reduce the probability of incorrectly accepting the null hypothesis (section 5.4.1). Regarding the studies in this review, their objectives were not necessarily to provide generalisable conclusions but to preliminarily investigate the useability and potential effects their novel AR educational tool could bring to educational settings. Therefore, some of the limitations motioned above, such as the generalisability and low participant numbers, may have less of an impact on the findings reported by authors.

A clear description of the development and, ultimately, the type of educational AR tool used was documented in 20 of the 22 articles. There were, however, two articles where the type of intervention tool was not explicitly reported (Chang and Yu, 2017; Smith and Friel, 2021). Instead, inference had to be made from the images in the articles that showed examples of how the systems functioned. Relying on images to convey the type of AR educational tool under evaluation leaves room for interpretation, possibly leading to incorrect classification. Ultimately, readers may not be aware of the functionality and purpose of the tool under evaluation. If there is a lack of understanding of the features and specifications of an intervention, it may be less likely for it to be replicated or integrated into wider educational settings.

All 22 studies were deemed to have appropriate study designs and methods however some studies reported their tools in greater detail than others, as will be discussed below. Most studies included an objective to evaluate the useability and perspectives towards the intervention tool and employed self-reporting data collection tools. Free text responses were not often used in the included studies, with more emphasis on short answer questions such as Likert scales. These questions helped obtain attitudes and feelings towards the AR educational tool but are associated with their limitations as they may not provide the opportunity to understand the reasons for participants' perspectives further. Depending on the types of questions used reliability and validity of questionnaire data collection tools may be difficult to obtain. Furthermore, it is also difficult to ensure that each question is read and interpreted the same by all participants (Drennan, 2013b; Roopa and Rani, 2012; Schwarz, 1995). As documented in table 2.5, nine studies were reported to have attempted to maintain an element of reliability by either calculating Cronbach's alpha or using a data collection tool that had previously been used or validated to gather data pertaining to the same phenomena. Participants may also not be able to place themselves in an absolute category when answering Likert statements, or they may answer with a particular response and not their genuine opinion, which ultimately can lead to a degree of untrustworthy findings.

A total of 22 studies employed some form of self-reporting evaluative questionnaire, 12 of those detailed one or more of the questions which were presented to their participants (M Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Gan *et al.*, 2018; Habig, 2020; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Salem *et al.*, 2020; Schmid *et*

al., 2020; Schneider *et al.*, 2020; Wong *et al.*, 2020). An additional seven articles, however, did not report any of the questions included in those evaluative surveys (Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Safadel and White, 2019; Sanii, 2020; Smith and Friel, 2021; Wozniak *et al.*, 2020). Chang and Yu (2017) referred to the standardised Short Feedback Questionnaire and the six analytical aspects but did not report the specific questions presented to participants. Macariu *et al.*, (2020) employed an established questionnaire for user interaction satisfaction (QUIS) but did not report the survey's specific questions. Without knowing what format and style questions are posed to participants, it becomes difficult to judge how valid these questions are to the objective and aims of the study. A level of reliability and validity of the results and conclusions of the study can be reported by using established questions, scales or even whole questionnaires. As table 2.5 documents, there was limited information provided concerning validated data collection tools. Over half of the studies did not report the use of validated tools or discuss the creation of new tools, as only four articles reported using Cronbach's alpha reliability score for their questionnaire. Further three studies employed a tool used in another study to measure a similar phenomenon (M Abdinejad *et al.*, 2021; Chang and Yu, 2017; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Salem *et al.*, 2020). Pilot studies can be used to test the validity and reliability of data collection tools; however, this was not reported to have been done before any studies commenced. Four studies, however, were disclosed to be pilot studies and reported the need for additional studies to confidently conclude their findings (Ovens *et al.*, 2020; Salem *et al.*, 2020; Schneider *et al.*, 2020; Wozniak *et al.*, 2020). Nevertheless, the lack of reported validated or established data collection tools may indicate that the 14 studies did not possess sufficient robustness to confidently report their findings (Aw *et al.*, 2020; Behmke *et al.*, 2018; Gan *et al.*, 2018;

Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Sanii, 2020; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020). A lack of reporting also extended to the themes uncovered during interviews. All three studies that used interviews did not provide general themes that emerged from the data during analysis (Chang and Yu, 2017; Macariu *et al.*, 2020; Wozniak *et al.*, 2020). The lack of reporting validated/established data collection tools, specific questionnaire questions, and themes that emerged from the interview data caused difficulty in measuring the quality of methods used to draw the conclusion made by the researchers.

Finally, the last limitation determined by the assessment criteria was a lack of additional explanations for the results obtained. Alternate possible explanations for findings were given in 11 of the 22 research articles; for example, prior knowledge of organic chemistry would have been an additional factor in reducing the reported cognitive load during post-test exercises (Aw *et al.*, 2020; Chang and Yu, 2017; Gan *et al.*, 2018; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Sanii, 2020). Furthermore, 13 articles did not provide an explanation of unanticipated outcomes. These outcomes, such as visibly reduced stress of participants when using the tools and negative sentiments towards the AR educational tool, may have been reported, but further exploration was not provided (Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Hou and Lin, 2017; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Sari *et al.*, 2021; Schmid *et al.*, 2020; Wong *et al.*, 2020). Exploring these unanticipated findings could have added additional dimensions to the research

articles. However, authors may not have been able or want to provide reasons as they may not have collected data that could be used to suggest potential explanations, or they may simply wish not to add subjectivity to their findings.

2.7 Chapter summary

This literature review was conducted to understand the breadth of research involving AR educational tools in chemistry, biology and Pharmacy higher education. Although there were a limited number of relevant articles, studies have been carried out across the globe demonstrating the interventions' universal qualities and application. The development and evaluation of AR educational tools have shown to be most prevalent in chemistry university settings. The review identified various styles of AR systems adapted to provide students with a novel presentation of educational concepts and phenomena, and a large proportion of included articles used mobile devices (smartphones and tablets).

Most studies employed evaluative surveys that included Likert scales and statements to measure perspectives in the performance of the AR intervention tools. Knowledge-based tests and assessments were used many times to determine understanding and performance; however, significant increases were only found in two studies. The majority of the studies included in this review detailed the creation and evaluation of the intervention. A small number compared the novel tool to either control groups or more established educational tools to provide content; however, it is still difficult to determine the usefulness of the intervention as only a small number of articles made direct comparisons.

Generally, the literature revealed positive attitudes and support for using educational AR systems in chemistry, biology, and Pharmacy in higher education. Participants largely reported AR systems as being generally easy and fast to use with a high degree of acceptance. The use of AR has been reported to improve motivation, visualisation skills, spatial skills, laboratory skills, knowledge, and the educational performance of users. It has also been reported to support current pedagogies such as collaborative and active learning within chemistry, biology and pharmacy and may contribute to new instructional approaches. However, further research is required regarding AR in education as the quantity and quality of literature are somewhat limited. Therefore, more focus should be placed on comparing AR with more conventional well-established forms of educational tools and its integration into the core of chemistry, biology and pharmacy education at college and university levels.

3 Aims and Objectives

3.1 Introduction

Before discussing the methodological considerations that surrounded this programme of research, it is essential to clearly outline the aims and objectives.

As highlighted in the summary of the previous chapter (section 2.7), further research on the use of AR in education was required due to the limited number of published high-quality research articles. This, along with the need to establish the ability of AR educational tools to support the education of biology, chemistry and pharmacy learners in HE. Furthermore, it was also critical to understand the criteria necessary for AR to be successfully implemented in educational environments. The points above led to seven collective objectives (listed below in section 3.2) and dictated the subsequent methodological and methodical considerations discussed in chapters 4 and 5.

3.2 Study Aims and Objectives

This research study aimed to evaluate the effectiveness of an augmented reality educational tool (Pharma Compounds) as a learning aid. In order to determine if the study aim was met, the following objectives were set;

1. To identify specific aspects of year 12 biology and chemistry content that students and tutors consider difficult to understand and visualise.
2. To identify specific aspects of Stage 2 Keele University MPharm content that students and tutors consider difficult to understand and visualise.
3. To develop a series of AR Pharma Compound cards whose design and content was informed by participant data (objective 1 and 2) for year 12 biology and chemistry

sixth form students and stage 2 MPharm students that will act as a learning/revision aid.

4. To quantitatively and qualitatively assess changes in self-reported motivation towards learning by sixth form students and MPharm students after the use of the AR Pharma Compounds tool.
5. To quantitatively and qualitatively assess the ability of the Pharma Compounds AR tool to enhance the knowledge of sixth form biology and chemistry and stage 2 MPharm students.
6. To qualitatively assess the perceived effectiveness, usefulness and useability of the Pharma Compounds AR tool in educational environments.
7. To triangulate the perceived and statistical changes in both knowledge and motivation towards learning that can be attributed to the use of the Pharma Compound AR tool.

The first three objectives relate to creating the AR intervention tool used in this research and will be addressed in chapter 6. The remaining four aims and objectives are then addressed in the results chapters (chapters 7, 8, 9 and 10) and thesis discussion (chapter 11).

As this research programme intended to incorporate both quantitative and qualitative approaches to develop and evaluate the educational AR tool of data collection and analysis, the following experimental hypotheses were suggested:

- The use of the AR Pharma Compound cards will improve year 12 biology and chemistry students, and stage 2 MPharm students' self-reported motivation towards learning.
- The knowledge of Year 12 biology and chemistry students and Stage 2 MPharm students will improve with the use of the Pharma Compound cards educational tool.

4 Methodology

4.1 Introduction

This chapter discusses the methodological considerations surrounding this piece of research. It begins with exploring philosophical perspectives in section 4.2 and follows into section 4.3, where the choice of methodology, quantitative, qualitative, and mixed methods research is discussed. Next, section 4.4 discusses the use of mixed methods in this research, and section 4.5 details the methodology of the chosen data collection tools. Finally, the issues surrounding the quality of research are discussed in chapter 4.6, with the chapter summary in section 4.7.

4.2 Philosophical Perspectives

Researchers' philosophical perspectives are mostly hidden within their writing. However, their viewpoints are typically governed by the type of research they conduct and can be inferred through their choice of methods if not made abundantly clear through their writing (Creswell and Plano Clark, 2011; Slife and Williams, 1995). Guba and Lincoln (1994) define philosophical perspectives as a collection of fundamental beliefs that address the initial principles of one's research. They believe the term embodies a researcher's worldview and defines the nature of the world, the individual's place in it, and the range of possible relationships between said world and its constituent elements.

Concerning philosophical perspectives, the term 'paradigm' may often be used alongside or in place of 'worldview'. Creswell (2008), in addition to a handful of other individuals, mainly used the term 'worldview' where the majority of writers and philosophers preferred the

term ‘paradigm’ (Lincoln and Guba, 2000; Mertens, 1998). Creswell (2008) described ‘worldview’ as the general perspective a researcher holds towards the world and research fundamentals. He believed that these views were shaped by the background and discipline of the researcher – this included the beliefs of the researcher, their advisers, their faculty or department and their past experiences. The phrase ‘worldview’ relates to the views and perspectives held by an individual researcher, whereas the term ‘paradigm’ refers to a comprehensive, widely accepted belief system or conceptual framework that defines how the world is viewed (Willis, 2007). The relationship between the two can be simplified as follows: paradigms are widely accepted worldviews held by many individuals (Mackinnon and Powell, 2008).

Exploring worldviews or paradigms requires first looking at two particular theoretical entities; ontology and epistemology. Crotty (1998) and Denzin and Lincoln (2005) described ‘ontology’ as the study of being that raises the fundamental questions surrounding the nature of reality and the nature of human beings in the world. It relates to ideas surrounding the existence of and relationships between humans, society and the world (Eriksson and Kovalainen, 2008). Epistemology, on the other hand, is the study of knowledge. The term encompasses the researcher’s understanding and ability to explain the knowledge they possess (Crotty, 1998). According to Denzin and Lincoln (2005), epistemological inquiry assesses the relationships between the researcher and what they know, posing the question, “how do you know the world?”, i.e. how does one make meaningful sense of the world?

From the epistemological and ontological views researchers hold, a classification can be made as to which paradigm their work would most likely align. Most works of research typically fall within at least one paradigm of principle philosophical assumptions but may overlap in instances where mixed methods are employed (Rolfe, 2013). Both quantitative and qualitative research can be linked to a number of paradigms but are usually associated with opposing epistemological and ontological perspectives. Research involving qualitative and quantitative elements is said to be founded on both extremes of philosophical assumptions (Frels and Onwuegbuzie, 2013).

Quantitative purists tend to hold perspectives that align with the positivism paradigm (Ayer, 1959; Maxwell and Delaney, 2004; Popper, 1959; Schrag, 1992). The perspective is that social observations should be investigated the same way a scientist would view and treat physical phenomena (Johnson and Onwuegbuzie, 2004). As such, positivist researchers believe positivism can be applied to the social world by providing the following assumptions; the social world can be studied in the same fashion as the natural world, that there are methods to study the social world without the beliefs of the researcher affecting their research, and that explanations of a causal relationship can be provided (Mertens, 2005). Nevertheless, quantitative purists maintain that all research should be conducted with the scientific model, where a theory or described experience is tested through observation and measurement to predict and control external factors, all while remaining detached from the investigation (O'leary, 2017). Positivist researchers maintain that social science inquiry should be objective with time and that the resulting generalisations be context-free (Nagel, 1986). According to this ideology, researchers should remove their bias and remain emotionally detached from research participants to justify or test the initial

hypothesis empirically. Positivist research predominantly generates objective data, so social and psychological phenomena may be perceived as having an objective reality. This reality is independent of the studied subjects and can enable the verification of the theory amongst other groups with the same characteristics – findings from positivist research often have a level of generalisability due to the objective nature of generated data and findings (Creswell and Plano Clark, 2011; Onwuegbuzie and Leech, 2005). The positivist paradigm was replaced by post-positivism after the second world war; this new perspective is based on the assumption that any piece of research is influenced by several well-developed theories, including the theory being tested (Cook , Campbell, Donald T., 1979; Mertens, 2005). Like positivists, post-positivists aim to achieve objective findings however they do so while acknowledging and addressing the impact their knowledge and theoretical biases may have on their work (Ryan, 2006).

At the other end of the spectrum, qualitative purists possess worldviews that generally align with constructivist or interpretivist paradigms (Johnson and Onwuegbuzie, 2004). Both paradigms share the general framework for human inquiry; however, there are nuances in how one would answer research questions (Schwandt, 1994). Interpretivism is the term that has been associated with contrasting epistemological views to those associated with positivism. Constructivism, on the other hand, is an idealist and pluralistic paradigm. It assumes that what is considered real is a construction in an individual's mind. These ‘real’ constructions may be multiple and often conflicting, nevertheless, all are considered meaningful (Guba and Lincoln, 1989). Interpretivists believe that the social sciences' subject matter is fundamentally different from those of the natural sciences (Bryman, 2012). As a result, investigations into social science phenomena require a different research logic that

encompasses and accommodates the intricacies of human nature. Constructivists also share this ideology, with the aim to understand phenomena by exploring the views and opinions of participants in an attempt to understand "the world of human experience" (Cohen *et al.*, 2011). This understanding of human experience leads to the development of different researchable theories compared to post-positivism, where investigations aim to explore a specific theory (Creswell, 2014; Mackenzie and Knipe, 2006). There are believed to be multiple perspectives and constructs of reality that are open to social interpretation, each view equal in importance to the next (Johnson and Onwuegbuzie, 2004; Onwuegbuzie and Leech, 2005). Additionally, constructivists believe that both time and context-free generalisations are neither desirable nor possible to attain, research is bound to a value, and it is virtually impossible to differentiate between cause and effect (Guba, 1990). Researchers who implement a constructivist worldview often position themselves as close as possible to the concepts and entities studied. This results from them believing that the researcher and the subject of the study are highly dependent on one another (Yilmaz, 2013).

Purist researchers, either qualitative or quantitative, may believe that their ideals and paradigms are archetypical for research, and maintain they could not and should not be mixed (Howe, 1988). Guba, for example, has long been seen as a leading qualitative purist with this view, as he wrote that "*accommodation between paradigms is impossible… we are led to vastly diverse, disparate and totally antithetical ends"* (Guba, 1990, p.81). However, mixed method approaches can be seen as being situated in the middle of a continuum where qualitative research is at one extreme and quantitative research is at the other (Creswell, 2008). When seen this way, mixed methods can take on philosophical

characteristics of both qualitative and quantitative worldviews, and so take a dual stance of some sort, and this is the basis of the philosophy of Pragmatism (Creswell and Plano Clark, 2011; Johnson and Onwuegbuzie, 2004). The focus of pragmatists tends to be on the 'what' and 'how' of research problems. They are not usually solely committed to any single reality or worldview, but place the research question at the centre and can then incorporate elements of quantitative, qualitative or both paradigms and methods, as is deemed best to answer the research question (Clarke and Visser, 2019; Cohen *et al.*, 2011; Onwuegbuzie and Leech, 2005; Robson, 2011; Savin-Baden and Howel Major, 2013). Although pragmatism is often seen as the philosophical framework that governs mixed methods research, some mixed methods researchers may associate themselves with other philosophical positions (Hunter and Brewer, 2003; Mertens, 2005). These include an a-paradigmatic stance, a multi-paradigm stance, and a single paradigm stance. An a-paradigmatic stance completely ignores paradigmatic assumptions as the researcher chooses not to take on a paradigmatic perspective or simply refrains from explicitly documenting their stance (Tashakkori and Teddlie, 2003). In the multi-paradigm stance, researchers draw on more than one paradigm. The third stance, single paradigm stance, where the mixed methods used are either all quantitative or qualitative.

As a point of clarity, pragmatist philosophical perspective was adopted for this doctoral research. Frost and Nolas (2011) highlighted that pragmatism enabled access to feelings, actions and thoughts that crossed with the issues of power, identity, meaning, interpretation and concurrent changes, both practical and material. In relation to this research, this philosophical approach was adopted because the feelings, actions, and thoughts of participants, together with the degree of changes in knowledge, behaviour, and

attitudes towards learning were all central to its objectives and therefore made a pragmatic approach suitable (Chapter 3.2). The pluralistic nature of pragmatism enabled generation of various data types (qualitative and quantitative), which were then brought together through triangulation to allow more insightful and meaningful conclusions to be reached than may have been reached by one sort of data alone.

Triangulation, as first coined by Campbell and Fiske (1959), can be seen as being a means of convergent validation. It had been previously used by quantitative researchers in work that adopted a mixed methods approach prior to its adoption by qualitative researchers (Fielding, 2012). Campbell and Fiske (1959) argued in support of using different measuring instruments in an empirical study to investigate a social phenomenon and to identify the convergent and divergent validities of the studied construct (U Kelle *et al.*, 2019). Triangulation has been criticised because different research methods typically depict the study participants in various ways, as qualitative and quantitative methods have different and often opposing epistemological and theoretical assumptions. Nevertheless, triangulation remains a critical part of a mixed methods approach; the collection of different types of data, typically quantitative and qualitative data (simultaneously and/or sequentially), and then comparing these sets of data to identify differences and similarities is the basis of triangulation (Gurbiel, 2018). Comparing various forms of data (numerical, textual, visual, multimedia) paints a broader and more detailed picture of the phenomena, significantly strengthening mixed methods as a credible research approach. The implementation of both qualitative and quantitative elements in this research programme allowed for the advantages of one approach to offset the disadvantages of the other, as discussed in sections 4.3.1 and 4.3.2.

As mentioned above, a mixed methods approach was adopted in this piece of research as it acknowledged the constructivist nature of the researcher's perspective and experience. Mixed methods also accounted for the objective, standardised perception of both the social and scientific elements of this study - changes in students' motivation and attitudes towards learning and changes in their knowledge from using the AR Pharma Compounds tool.

4.3 Choice of Research Methodology

The term 'methodology' refers to the specific framework in which research is conducted. Crotty (1998 p.7) defined the term as *"…The research design that shapes our choice and use of particular methods and links them to the desired outcomes… Not only a description of methodology but also an account of the rationale it provides for the choice of methods and the particular forms in which the methods are employed."* It is important to note that methodology differs from the 'methods' one would use in research. The term 'methods' refers to specific techniques, and tools researchers use to collect and analyse data. The methods used in this research are discussed in Chapter 5.

4.3.1 Quantitative Research

Quantitative research quantifies and analyses variables to obtain results (Leedy and Ormrod, 2001; Williams, 2011). It usually begins with researchers identifying an area of a subject that presents a specific research question they aim to answer, often after careful review of research literature and developing hypotheses (Neuman, 2000). Data collection within quantitative research typically involves the researcher carefully recording and verifying numerical information (Choy, 2014). Various statistical techniques are then used to

analyse numerical data to answer 'how, what, when, where, who, how many and how much' (McCusker and Gunaydin, 2014). Aliaga and Gunderson (2002) described quantitative research as *"the explaining of an issue or phenomenon through gathering data in numerical form and analysing with the aid of mathematical methods; in particular statistics."* Although Aliaga and Gunderson state that quantitative data is numerical, it can include numerically coded textual raw data. Ultimately, quantitative research aims to tackle a phenomenon through numerical data subject to mathematical (statistical) analysis proving a hypothesis true or false.

Quantitative research, usually takes an objective perspective of the social world. Kerlinger's (1979) definition of 'a theory' in terms of quantitative methodology stated *"a set of interrelated constructs, definitions and propositions that presents a systematic view of phenomena by specifying relations among variables, with the purpose of explaining natural phenomena"*. Creswell (2014) elaborated on this definition and added that the constructs were formed into hypotheses that specified the relationship between variables, most notably concerning magnitude or direction. He went on to say that these theories were often put forward as an argument or a rationale.

Quantitative research has its strengths and limitations. The strengths are related to the numerical nature of its data; numerical data sets can be quickly gathered and easily compared to one another to determine similarities or differences between groups (Forman *et al.*, 2008). A second strength of quantitative research is that data collected and analysed with appropriately rigorous methods can be highly reliable (4.6.1) (Choy, 2014). On the other hand, numerical data also contributes to the shortcomings associated with

quantitative methodological approaches. Although quantitative research may employ rigorous and controlled methods to examine phenomena, it often lacks depth as participants' perspectives and beliefs cannot readily be reduced to numbers (Dudwick *et al.*, 2006; McCusker and Gunaydin, 2014). This lack of depth is not necessarily a weakness but rather a limitation as a result of the nature of quantitative research by design – a line of inquiry to produce objective generalisable results and findings. While statistical tests may be performed on the effects caused by the intervention, the reasons why the intervention had such an effect are not usually explored, which can lead to a lack of context and understanding (section 4.6.1) (Choy, 2014; Dudwick *et al.*, 2006).

The use of quantitative methods was deemed to be a workable methodological approach in this research, as AR use in chemistry, biology, and pharmacy HE has not been widely researched and would require an objective investigation into measurable variables. The lack of research in this area pointed to the need to conduct research that would objectively depict the degree to which AR can improve the learning of HE students with respect to changes in knowledge, motivation towards learning and its usefulness. Therefore, numerical measurements associated with these variables among biology and chemistry sixth form students, as well as undergraduate pharmacy students were considered to be a vital component of this study. Statistical analysis of quantitative data was the most appropriate approach in identifying any significant changes to participants' knowledge as a result of using the AR educational tool.

4.3.2 Qualitative Research

The term 'qualitative methodology' broadly refers to research that generates descriptive data – i.e., participants' writing, spoken words and observable behaviour. Researchers who employ qualitative methodologies tend to be interested in the meanings that participants attach to things, phenomena and experiences in their lives; through these methods, researchers can strive to understand participants' reality or lived experience and frames of reference (Corbin and Strauss, 2008; Levitt *et al.*, 2017). Blumer explained how qualitative researchers may try to empathise and identify with their participants, whilst simultaneously trying to "*catch the interpretative process by remaining aloof as a so-called 'objective' observer, refusing to take the role of the acting unit and risking the worst kind of subjectivism – the objective observer is likely to fill in the process of interpretation with their own surmises in place of catching the process as it occurs in the experience of the acting unit which uses it*" (Blumer, 1986, p.g 86). This suggests that qualitative researchers should ground their interpretations in participants' words or actions (or both), rather than giving primacy to their own perspectives and views on the studied phenomenon, to reduce confirmation bias. A researcher can achieve this by keeping a clear and detailed report of decisions and the rationale behind those decisions (Berger, 2013). Other strategies include repeat interviews with participants, peer reviews, formation of support groups and networks, maintaining a journal for self-supervision, triangulation and member checking, which help to increase the level of reflexivity within research (section 4.6.3) (Bradbury-Jones, 2007; Fonow and Cook, 2005; Padgett, 2008).

Qualitative research has been associated with more than one paradigm or worldview and may or may not have a defined set of methods exclusive to itself (Denzin and Lincoln, 2011).

Qualitative research may begin with a research question that encompasses one or more topics, but typically places focus on participants' understanding of meanings and social phenomena within a particular context. The researcher's theoretical perspectives (gained from previous research findings or theories relating to a specific set of concepts and relationships) are often closely linked to the research programme's goals (Mohajan, 2018).

Data generated by qualitative research is usually more descriptive in comparison to data generated through quantitative research. Most often, its source is from real world scenarios (Mohajan, 2018). It is largely inductive by nature as researchers develop understandings, insights, and concepts from patterns in rich and varied data sets. This can afford a greater understanding of social entities and constructs; however, this understanding is within the context of a specific population, and therefore comes with the understand that generalisable conclusions cannot necessarily be made and may also prevent one from drawing conclusions of statistical significance (section 4.6.2) (Braun and Clarke, 2013; Bryman, 2012; Johnson and Onwuegbuzie, 2004). It should be noted that the likely transferability of qualitative research findings to another population depends on the similarity of the context, which is a judgement that must be made by the reader - The inclusion or reporting of reflexive practices helps readers make that judgement.

Considering both the features and affordances of qualitative approaches when identifying research methods is paramount to the success of a study (Johnson and Onwuegbuzie, 2004). A few key strengths associated with qualitative research documented by Yauch and Streudel (2003) and Creswell (2014) are as follows: open-ended questioning can be used to explore new and unanticipated phenomena and ideas; it allows researchers to explore the

views of both homogenous and heterogenous groups of participants; it can play a critical role in the formation of suggested relationships between groups to dissect perspectives and build detailed pictures of social phenomena; it provides insight into the causes and directions of casual relationships. The features of qualitative research are suited to an explorative line of inquiry (the exploration of the depth and breadth of a phenomena) over generalisable findings. Qualitative research is robust in its processes however concepts such as rigour, validity and reliability are largely quantitative concepts. This is not necessarily a weakness of qualitative research as it has as methods to maintain reliability and validity (section 5.6.1 and 5.6.2) (Bowen, 2006; Morse, 2015; Yauch and Steudel, 2003). With respect to open-ended questioning such as those used in interviews, participants are more in control over the content of the data that has been collected and further aligns the explorative social construct line of inquiry. Ultimately the choice of methodological research approach is dictated by the nature of the research question.

Research surrounding AR's use in biology, chemistry, and pharmacy HE has so far been relatively limited, and its effects on an individual's ability to learn still requires a much deeper understanding. As a result, qualitative research methods were considered appropriate for this research to explore how the Pharma Compounds AR educational tool altered individuals' learning processes and, in turn, how these changes affected learners' attitudes towards learning, as well as the AR tools perceived effect of education from the perspectives of tutors.

4.3.3 Mixed Methods Research

In an attempt to uncover answers to research questions, studies and projects often contain multiple aims and objectives. Using a singular methodological approach can make the search for answers more difficult, and in some cases, the answers may not be fully explored (Johnson and Onwuegbuzie, 2004). As a result, mixed methods may offer an opportunity to explore phenomena and answer research questions in greater depth.

Johnson and Turner (2003) emphasised that a good understanding of both the strengths and limitations of quantitative and qualitative research is essential for one to be able to effectively mix the two approaches to gather data. The resulting combination compounds the strengths of both disciplines and minimises the limitations of each respective methodological approach such that they are negated or that they do not overlap (Creswell *et al.*, 2003; Creswell and Plano Clark, 2011; Johnson and Onwuegbuzie, 2004; Onwuegbuzie and Leech, 2005). Correct use of Johnson's and Turner's (2003) principle is a major justification for using mixed methods in research. For example, quantitative research can often lack the ability to provide understanding in terms of context. This lack of understanding can be addressed by including qualitative elements that enable exploration into participants' views and perspectives, thus providing context to the quantitative results. At the other end of the spectrum, qualitative data is often subject to the researcher's interpretation. This contrasts with quantitative research, where researchers actively maintain objectivity to not express their perspectives through their interpretation of the result and its subsequent findings. The use of mixed methods affords researchers to make generalisations about a population (typical of quantitative research) and, at the same time, provides a detailed exploration into the researched phenomena and its concepts (typical of

qualitative research) (Creswell and Plano Clark, 2011). As mentioned, triangulating the findings of both qualitative and quantitative methods that support one another only adds to the strength and confidence of the drawn conclusions (O'Cathain *et al.*, 2007). However, mixed methods aim not to identify corroborating findings but rather to expand ones understanding of the research phenomena in both its magnitude and context (Greene, 2008; Onwuegbuzie and Leech, 2005). If the opposite occurs and the findings conflict, the researcher will have obtained greater knowledge and can modify interpretations and conclusions accordingly.

4.4 Mixed Methods in this Research

This research programme adopted a mixed methods approach to investigate the main research objective: to evaluate an augmented reality educational tool (Pharma Compounds) in Biology and Chemistry Sixth Form education and Stage 2 Pharmacy education. This evaluation not only aimed to evaluate changes in knowledge by also aimed to examine elements of students learning that contributed to the learning experience – motivation, students' level of enjoyment, the novelty of using an AR educational tool, and participants' perspectives towards learning (Chapter 5.2).

As mentioned in the previous section (4.3.3), a mixed methods approach combines the methodology of both qualitative and quantitative disciplines, data collection and data analysis tools. The limited number of papers researching augmented reality in biology, chemistry and pharmacy education used different quantitative and qualitative methodologies (Chapter 2.5). A larger proportion of studies included in this thesis' narrative review adopted a mixed methods approach (Behmke *et al.*, 2018; Chang and Yu, 2017;

Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Reeves *et al.*, 2021; Schneider *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020; Yapici and Karakoyun, 2021). As a result, mixed methods methodology has proven to be effective in evaluating novel AR educational tools in biology, chemistry, and pharmacy HE. Therefore, its use in this research was deemed appropriate to evaluate the Pharma Compounds AR tool in the same subject areas. The qualitative and quantitative aspects of the mixed methods approach strengthen the conclusions made in this thesis (chapter 11) and offset the weaknesses associated with each of the individual methodologies.

The decision to use mixed methods to evaluate the impact of the Pharma Compounds AR tool on participants' knowledge of subject material and its effect on perspectives and motivation towards learning was supported by the supervisory team. The use of mixed methods enabled the statistical effectiveness of the AR educational tool to be measured and the perspectives and motivations towards learning of participants to be explored. The varied qualitative and quantitative data sets collected through knowledge-based quizzes and questionnaires allowed for direct comparisons between changes in participants' thoughts, perspectives and perceived knowledge and their actual changes in knowledge.

Focus groups were initially going to form the final data collection stage to gain a deeper understanding of participants' experiences throughout the intervention period. This was amended to one-on-one semi-structured interviews due to complications caused by the COVID-19 pandemic (effects of COVID-19 discussed in more detail in chapter 11.5). Triangulation of the knowledge-based quiz data, questionnaire data and interview data allowed for the cross-referencing of themes and ideas that provided possible reasons for

the changes experienced by participants after the use of the intervention tool – qualitative results from questionnaires and interviews could be used to potentially explain changes in knowledge, performance in the quizzes and motivation towards learning. Therefore, conclusions were made with greater certainty and validity (Gurbiel, 2018; U Kelle *et al.*, 2019).

4.5 Methodology of Data Collection Tools

This mixed methods study utilised a one group pre- and post-intervention format, similar to those used in several studies that investigated ARs use in biology, chemistry and pharmacy higher education (Aw *et al.*, 2020; Hou and Lin, 2017; Schneider *et al.*, 2020; Wong *et al.*, 2020). In order to evaluate the Pharma Compounds AR tool, participants' knowledge, attitudes and perspectives towards learning were assessed and explored both before and after the intervention period. Three data collection methods were employed across the pre- and post-intervention periods: 1) questionnaires, 2) knowledge-based quizzes, and 3) semi-structured interviews. Questionnaires were carefully designed with a variety of question formats that gathered both quantitative and qualitative data from participants regarding their perceived knowledge, attitudes, and perspectives towards learning, before and after the introduction of the Pharma Compounds AR tool. The questionnaires also collected quantitative data that was statistically analysed to identify self-reported changes in attitudes and motivation towards learning after the AR tool was introduced. Pre- and post-intervention knowledge-based quizzes enabled changes in actual participant knowledge to be identified. These changes were then statistically analysed to measure the degree of significance between the two sets of quiz results. Finally, semi-structured video call

interviews contributed to developing a deeper understanding of student and tutor perspectives towards learning with and without the Pharma Compounds AR tool.

Qualitative and quantitative data were collected both simultaneously and sequentially. The quizzes (quantitative) and questionnaires (quantitative and qualitative) were used to collect data before and after the intervention period. The interviews (qualitative), however, were conducted after the completion and analysis of the questionnaire data as participant responses informed the development of the interview protocol. The qualitative data collected held equal weighting to the quantitative data (equal status design) as the impact the intervention tool had on participants' motivation and perspective towards learning were deemed to be of equal importance as the actual impact the tool had on knowledge (Creswell and Plano Clark, 2011).

4.5.1 Pre- and Post-Intervention Questionnaires

Questionnaires are probably the most widely known and used data collection tool, not just in educational research but in most pieces of research that aim to obtain the perceptions and beliefs of its participants (Taherdoost, 2016; Vilanova, 2006). Questionnaires enable researchers to gather a multitude of data, most notably data surrounding participants' behaviours and attitudes (Bee and Murdoch-Eaton, 2016; Tavakol and Sandars, 2014). A variety of question types can be used in questionnaires to gather either purely qualitative or quantitative data and, in some cases, a mixture of the two in varied proportions. These include contingency/cascade format, matrix, closed-ended, and open-ended questions (Goode and Hatt, 1952). Contingency-type questions are answered by participants who provided a particular response to a previous question; this prevents participants from

responding to questions that do not apply to them. Matrix questions have a format where identical response categories are listed at the top of a page and are assigned to a list of multiple questions. Participants a required to select the most appropriate response for each question in the matrix list. Closed-ended questions limit participants to a fixed set of responses. They are often presented as yes/no, multiple choice, and Likert-scale questions (Roopa and Rani, 2012). On the other hand, open-ended questions require respondents to reply in their own words without restriction (De Vaus and de Vaus, 2013; Kothari, 2004). Questionnaires allow researchers to gather data from large numbers of participants in a relatively short time, capturing their perspectives and experiences regarding the research phenomena. Although the objective of using a questionnaire is not to make generalisations about the larger population, it is possible to extend one's findings if there is a large enough sample size (Braun and Clarke, 2013; Bryman, 2012).

Questionnaires were decided to be an appropriate method to gather participants' views, opinions, and self-reported motivation levels through closed and open-ended questions. Themes and ideas found in participants' responses to the open-ended question provided context to the statistical findings from the pre- and post-intervention quizzes (Chapter 9.4). These same themes were also further explored through the semi-structured video call interviews with student and tutor participants (Chapter 10 explores all the themes that emerged from the interview data). Despite questionnaires possessing the ability to gather a wide range of data, they also have their shortcomings. Compared to interviews, questionnaires are often highly structured in that questions are posed in a uniformly systematic order irrespective of the participant's responses (Phellas *et al.*, 2011). Questionnaires can sometimes lack the ability to delve deeper into the meanings behind

participants' responses at the instance of completion if a response is not completely clear or understood by the researcher. This miscommunication can hinder the questionnaires' ability to explore participant perspectives. Additionally, questions that are included in questionnaires are open to the interpretation of the respondent, further affecting the value of the data; piloting the surveys can help improve the validity of the tool, but misinterpretation of the questions may still be a factor (Drennan, 2013a; Roopa and Rani, 2012; Schwarz, 1995). Nevertheless, questionnaires remain a popular data collection tool for gathering social groups' views and perspectives. A questionnaire was considered a useful method of data collection in this research as a vast amount of data, locally and internationally (chapter 5.2), can be gathered within a short time (Phellas *et al.*, 2011). Questionnaires ensure that each participant is presented with an identical set of questions in precisely the same format ensuring uniformity amongst all participants. Data gathered through this tool contributed to the triangulation process, along with data gathered from the other two data collection tools.

Online questionnaires was identified as the most ideal form of survey due to the advantages compared to postal or paper-based questionnaires. Provided participants have adequate IT equipment online questionnaires present minimal costs on behalf of the research team as questionnaires can be accessed centrally online and do not require physical forms to be printed and posted to various locations (chapter 5.7 discusses the online platform, Google Drive, that was used host the online questionnaires and quizzes) (Nayak and Narayan, 2019; Phellas *et al.*, 2011). Therefore, web-based questionnaires can easily be distributed and administered to large numbers of participants across the globe. Furthermore, data from online questionnaires are collected automatically and held centrally at the point of

submission. This simple function of web-based questionnaires streamlines the data collection process (Nayak and Narayan, 2019). Additionally, platforms like Google Forms (used in this research) display submitted participants' data to the researcher in different charts and graphs for visual representation (Duffy *et al.*, 2005; Wright, 2005). This automatic generation of graphs and charts from collected data provides researcher with an initial visual representation and spread of the data before conducting a more in-depth analysis. The use of paper-based questionnaires would have added an additional step to the data collection process compared to web-based forms as the physical questionnaires would have to be returned to the researcher and securely stored – online-based questionnaires hosted on the Google Drive Forms platform are securely stored and password protected. If used, some participants may complete the paper-based survey but fail to post or return the questionnaire to the research team. Should the surveys be returned via post, they would be at risk of being misplaced in transit and be susceptible to data protection violations, resulting in lost data. Anonymised questionnaires would help to limit data protection violations; however missing data could impact comparative studies with a pre- and post-format. Ultimately the use of the online platform may improve participant response rates. A more streamlined process to complete and return questionnaires may be more appealing to participants as opposed to a more laborious, process such as manual postage.

4.5.2 One Group Pre- and Post-Intervention Assessments

As this programme of research investigated the Pharma Compound AR app as an educational tool and compared changes in knowledge before and after the intervention period, a quasi-experimental design was chosen. Quasi-experiments enable researchers to compare the effect of an intervention against either another intervention or no intervention

at all – the effect of the independent variable (Pharma Compounds AR tool) on the dependent variable (knowledge of quiz material) was measured (Maciejewski, 2020). Generally, participants are not required to be randomised or matched into groups when performing quasi-experiments, but the absence of random assignment to groups can cast doubt on the study's internal validity (section 4.6.2). However, the inclusion of a pre-intervention quiz that assessed participants' knowledge of quiz topics increased the validity of the quasi-experiment as the scores from the pre-quiz formed a baseline level of performance that was used to compare the scores of participants after the intervention period (Maciejewski, 2020; Shadish *et al.*, 2002). It should also be mentioned that heterogeneity between the number of participants who complete pre- or post-elements may be expected and impact the validity of the quasi-experiment (Maciejewski, 2020). However, this was adjusted at the analysis stage to maintain the validity and account for the differences between the groups by matching the pre- and post-results (chapter 5.8.2) (Maciejewski, 2020). Nevertheless, results of quasi-experiment studies that employ pre- and post-design can provide valuable findings because the intervention is not artificially inserted into social settings and therefore has a very strong ecological validity (Bryman, 2012).

Bryman (2012) noted that independent variables could be challenging to manipulate, particularly in social research. A number of factors may have impacted learning and, thus, the knowledge scores of participants in this study – factors may include sector and level of education, country of education, support from tutors, the individual's intentions, habits, and learning process. Although some of these factors have been reported in this thesis (age, gender, sector, and country of education) (sections 7.2, 7.4, 8.2, 8.4, 9.2, 9.3 and 10.2),

others could not be accurately measured or accounted for when baseline results were collected (e.g. support from tutors and the intentions of the participant).

Although randomised control trials (RCTs) are considered the gold standard of experimental research, especially in health-related fields, an RCT was not chosen to evaluate the AR educational tool on pragmatic grounds (Bryman, 2012). RCTs are similar to quasi-experiments in that they compare the effects of one intervention against that of another or no intervention (Maciejewski, 2020). One factor that sets RCTs apart from a quasi-experiment is the ability to alter the independent variable to identify any effect on the dependent variable. Authentic experiments incorporate randomly assigned participants into intervention and control groups to remove any potential expectation of a group's performance during the experiment that could lead to bias (Bryman, 2012). Due to the need to have a control group, an RCT was deemed to be unsuitable for this piece of research. It may have been possible to randomly assign participants into intervention and control groups. However, the difficulty would have been preventing those in the control group from encountering the intervention tool during the extended intervention period — this project involved participants who were taught in multiple classes and schools across two countries. The initial intention was to include participants from three countries however logistical issues brought about by COVID-19 reduced participation to two countries (Chapter 11.5). It would have been impractical to have half of each class use the intervention tool and have the second half form the control group. The research team would not have been able to ensure that participants from the control groups did not have access to or use the intervention tool, therefore, an RCT was not considered appropriate.

The pragmatic quasi-experimental design consisted of a one group pre- and post-intervention knowledge-based quiz which generated comparable scores to assess changes in knowledge before and after the use of the Pharma Compounds AR tool. The popularity and success of such experiments when used to evaluate educational learning tools have been documented in the literature involving AR (Akçayır *et al.*, 2016; Aw *et al.*, 2020; D. T. Campbell and Stanley, 1963; Enyedy *et al.*, 2012; Gan *et al.*, 2018; Hou and Lin, 2017; Jou and Wang, 2013; Keller, 1987a; Keller *et al.*, 2021; Martín-Gutiérrez *et al.*, 2015; Rosenbaum *et al.*, 2007; Schneider *et al.*, 2020; Sotiriou and Bogner, 2008; Wong *et al.*, 2020). Although quasi-experiments do not always incorporate control groups, they can incorporate a 'non-equivalent control group design' – participants are non-randomly assigned into control and intervention groups at the beginning of the study (Drennan, 2013a; Shadish *et al.*, 2008). However, using a typical control group was considered somewhat impractical and inequitable. For example, participants in the control group would not have had access to the tool in the build-up to their exams or during their assignments. Although public examinations (A-level) occur at the end of the academic year, other assessments occur at various points of the year. It was unknown to the lead researcher when these internal examinations and assessments (e.g., A-level mock and MPharm undergraduate exams) would have taken place, therefore, if a control group had been adopted, it may have been possible that some students would not have had the opportunity to use the AR tool before sitting their assessment with a cross over study approach. Therefore, the pre- and post-intervention knowledge-based quiz format offered a solution in that the pre-quiz scores provided participants' baseline knowledge that could be compared to the post-intervention quiz scores.

4.5.3 Video Call One-on-one Semi-Structured Interviews

A number of qualitative data collection methods were considered in order to better understand participants' views and perspectives on the AR educational tool. As mentioned in section 4.4, focus groups were initially considered an appropriate tool to further explore perspectives expressed by participants in the questionnaire. Researchers have documented how focus groups have been an efficient, cost-effective tool used to gather vast amounts of rich data related to a specific phenomenon (Bertrand *et al.*, 1992; Carey and Smith, 1994; Cyr, 2015). A critical characteristic of focus groups that sets them apart from other qualitative data collection methods is the interactions between participating individuals (Bloor *et al.*, 2001). The moderator would play a vital role in assisting each participant to identify their perspective on which they are to reflect (Acocella, 2012) and encourage interactions between participants (Puchta, 2005). Contributions made by members of focus groups may encourage more timid individuals to share their thoughts and help direct the course of discussions (Stewart *et al.*, 2006). Moreover, focus groups would also have allowed participants' similar or conflicting views and opinions to be directly discussed, sparking new thoughts and dialogue (Braun and Clarke, 2013). Focus groups, however, are not without their limitations. Although group sessions can provide a sense of security to introverted participants, as mentioned above, they can also have a negative effect on timid personalities. More dominant individuals can take control of the discussion forcing their perspective to project with greater force, resulting in the more timid participants withholding their opinions, which means that to be inclusive of all participants' contributions, focus groups need skilful facilitation (Bryman, 2012; Creswell, 2007). Nevertheless, focus groups were considered as an attractive data collection method to further explore participants' perspectives and experiences using the Pharma Compounds AR

tool from socially dynamic environment. Although there is evidence that suggests online focus groups may generate similar levels of social interaction to in-person focus groups (Stewart and Shamdasani, 2017), logistical difficulties in the executions during the early lockdown phases of the COVID-19 pandemic were considerable. Therefore video call interviews became the most feasible method of data collection for this phase of the research programme.

Aside from qualitative questionnaires, interviews have been frequently used to collect data regarding AR tools in science, healthcare HE and social science qualitative research (Chang and Yu, 2017; Low, 2013; Macariu *et al.*, 2020; Wozniak *et al.*, 2020; Yang *et al.*, 2018; Yapici and Karakoyun, 2021). Commonly, structured interviews require the development of a strictly followed protocol to ensure each participant is asked the same questions in the same order with the same wording (Berg, 2007; Phellas *et al.*, 2011). With regards to semi-structured interviews, the interview guide forms somewhat of a protocol for the direction of the interview, whereas unstructured interviews may not have a protocol at all (Jamshed, 2014). Similar to focus groups, both semi-structured and unstructured interviews can accommodate the exploration of unexpected responses and perspectives shared by participants as the protocol covers themes that should be covered but not necessarily specific questions or their order (Phellas *et al.*, 2011; Rubin and Rubin, 2005). Ultimately the choice of interview method depends on the overall research aims and the nature of the questions to be asked. An aim of this research programme was to qualitatively assess the perceived effectiveness, usefulness and useability of the Pharma Compounds AR tool. To address this aim, a deep understanding of participants' experiences and perspectives towards learning, both before and after the introduction of the intervention tool was

needed. Therefore semi-structured interviews were deemed appropriate; this would allow for the exploration into nuanced and unanticipated perspectives shared by participants.

In addition to the structure of the interviews, the setting in which they are performed is also important. Face-to-face interviews conducted via online video calls were preferred over telephone interviews. Unfortunately, it was logistically impossible to conduct the interviews in person due to COVID-19 social distancing measures that had been put in place. Face-to-face (via video call) interviews were chosen over telephone interviews as they have been successfully used in qualitative research that heavily relied on the verbal accounts of their participants (Oakley, 1998; Taylor *et al.*, 2016). This data collection method had an increased benefit as the lead researcher could simultaneously take advantage of voice intonation, body language and facial expression, providing additional context to the participants' quotes (Opdenakker, 2006). This additional layer of information would have otherwise not been accounted for if telephone interviews had been used. It is also key to note that the interviews conducted via online video calls presented the opportunity to extend participation to all participants during the social distancing measure brought about by the COVID-19 pandemic (Mann and Stewart, 2000).

Like every method of data collection, interviews have been associated with their share of limitations, particularly those related to the one-on-one dynamic as well as the location of the participants. Conducting one-on-one interviews is inherently time-consuming as only one participant can be interviewed at a time. Therefore it is not anticipated that a researcher to be able to conduct a large number within a restricted period (Alsaawi, 2014). Concerning timing and location, interviewers would have to arrange a time and location

that would be suitable for both parties to participate. This can be problematic with face-to-face interviews as participants can be situated in different locations with conflicting timetables. Videocall interviews ease the organisational dilemma and negate the need to arrange a location. The interviewer and participant can be in two separate locations and organise a time that best suits both parties (Mirick and Wladkowski, 2019). There are also costs associated with face-to-face interviews that can limit participation size and geographical coverage (Phellas *et al.*, 2011). Although video call interviews helped to counteract the geographical issues and provide an element of convenience for interviewees, it may have presented an additional cost as participants needed access to a computer and the internet to participate. A further concept associated with interviews was the subconscious bias that may have emerged from several sources; the style in which questions were posed, the personal characteristics of the interviewer, and participants providing responses they think the interviewer wanted to hear (Brown, 2001; Phellas *et al.*, 2011). Therefore, researchers can attempt to reduce their impact and bias on participants by using a reflexive approach to identify and articulate their influences on participants behaviour and responses (Chapter 4.6.3).

4.6 Quality of Mixed Methods

Considerations surrounding the specific study design, data collection and data analysis methods are discussed in the next chapter (Chapter 5). The following sections of this chapter explores the issues of quality of mixed methods research methodology, which is required to ensure that research is conducted robustly (Heale and Twycross, 2015). In relation to quantitative research, quality or rigor relates to constructs of reliability (section 4.6.1), validity (section 4.6.2) and generalisability (section 4.6.2) (Zohrabi, 2013). With

respect to qualitative research these concepts are not uniformly applicable and as such, different criteria are used to measure quality (i.e., coding systems, inter-rater reliability, and trustworthiness – discusses in section 4.6.1)) (Lincoln and Guba, 1985; Zohrabi, 2013). Some researchers on the other hand (e.g., Morse, 2015) advocate using both validity and reliability as measures of quality in qualitative research which is discussed in section 4.6.1 and 4.6.2. As a means of using broadly consistent measures of quality across all parts of the mixed methods study, the same approach used by Morse (2015) was adopted in this programme of research while being mindful of how authors caution the use of rigor as a measure of quality in qualitative research.

4.6.1 Reliability

Data reliability is generally considered one of the main characteristics of effective quantitative research (Zohrabi, 2013). Reliability relates to the consistency, dependability and replicability of results obtained from a research study and can be measured in a number of ways depending on the nature of the research (Nunan, 1999; Zohrabi, 2013). Precise calculations of reliability cannot be provided in quantitative research. However, an estimation can be achieved by measuring three different attributes – Internal consistency, stability and equivalence (Heale and Twycross, 2015). Internal consistency, or homogeneity, refers to the uniformity and fidelity of data collection tools and the data collection process. (Bryman, 2012). Researchers can use any of the following methods to obtain a representation of internal validity for their quantitative questionnaire data collection tool – split-half reliability, Kuder-Richardson coefficient, or Cronbach's alpha. Compared to the other methods, Cronbach's alpha is extremely popular amongst researchers due to its relative simplicity (Tavakol and Dennick, 2011). Calculating Cronbach's alpha is done by

taking the averages of all correlations in every combination of Likert scale items, resulting in a value between 0 and 1. A score of 0.7 and higher is considered to be acceptably reliable (Heale and Twycross, 2015; Tavakol and Dennick, 2011). Although the length of a scale can impact the outcome of the calculation, a low score could be due to a low number of questions within the scale as opposed to poor inter-relatedness between items (Tavakol and Dennick, 2011). Cronbach's alpha was the chosen method to assess the reliability of the quantitative questionnaires used in this piece of research due to its simplicity and prior use in published literature (Chapter 2.6, Chapters 8.3.1, and Chapter 8.5.1).

Stability is the agreement of a measuring instrument over time and is most commonly tested using the test-retest method (Bryman, 2012). This method assesses reliability when a data collection tool is given to the same participants on more than one occasion under similar circumstances. Statistical comparisons between the instrument scores at each occasion of completion indicate the reliability of the instrument (Bryman, 2012; Heale and Twycross, 2015). The pre- and post- format of this study provided test-retest stability for quantitative data as the post-intervention elements were statistically compared to the pre-intervention elements (Chapters 7.3, 7.5, 8.3.2 and 8.5.2). The last method, equivalence which relates to the consistency with which a construct can be measured by two or more different tools. For example, data collection tool, A and data collection tool B measure the same concept. Participants complete respond to data collection tool A and B, the responses of which are correlated and compared.

Reliability in qualitative research, however, is different. Achieving almost identical results in qualitative research is inherently unlikely due to the subjective and constructed nature of data (Zohrabi, 2013). Lincoln and Guba (1985) argued that it would be more reasonable to look at the data's credibility (the "fit" of respondents views and the researcher interpretation of them (Tobin and Begley, 2004)) and dependability (logical, traceable and clearly documented research process (Nowell *et al.*, 2017)). Therefore, reliability in qualitative research does not necessarily mean one can obtain exactly the same or even highly similar results but signifies that the data collection process, the results and findings are consistent and dependable (Braun and Clarke, 2013; Bryman, 2012; Denzin and Lincoln, 2005).

Morse (2015) critically analysed the methods used by researchers to try and ensure rigour within qualitative research. Her article outlined various methods that had been employed to ensure assurance of both reliability and validity in qualitative research. According to Morse (2015), the major methods by which reliability was determined stemmed from the coding process, and as a result, the most commonly used strategies were the development of coding systems, respondent validation and inter-rater agreement. These strategies are by no means a 'gold standard', as researchers can choose the most appropriate strategies based on their data collection tools and requirements.

Inter-rater agreement, sometimes known as investigator triangulation, is a strategy that aims to ensure a degree of reliability through the agreement of researchers concerning coding data (Campbell *et al.*, 2013). This approach may be most appropriate when more than one researcher is involved in the data collection and analytical processes. Inter-rater

reliability involves a process where researchers qualitatively determine the level of agreement concerning a 'unit' of data and whether it has been appropriately coded - a form of "moderation" (Bryman, 2012; Heale and Twycross, 2015). However, its appropriateness has been questioned due to the assumption that coding is subjective – the researcher's hypothesis, framework, or background knowledge would inescapably influence the coding process (Guba and Lincoln, 2005; Smith and McGannon, 2018). Therefore, themes that emerged from data gathered from qualitative questionnaires and interview transcriptions were shared and discussed extensively with the supervisory team as part of refining the coding framework used for analysing interview data to ensure 'inescapable influences' were reflexively acknowledged, and the arrangement of all codes/themes in the framework was agreed with the supervisory team were to achieve a level of reliability.

An additional method used to increase the trustworthiness and reliability of qualitative data was for researchers to have kept a detailed record of all phases and elements of their research programme, this includes thoughts and decision made e.g. during the coding of data (Bryman, 2012). Interview audio recordings can also increase the study's reliability as it is an accurate record of the conversation and participant responses (Tobin and Begley, 2004). As a result, transcripts were double checked against each audio recording and reconciled with the interview notes for accuracy. Annotated in square brackets were added to the transcriptions with non-verbal communications that were considered significant (such as emotional reactions, gesticulations, and long pauses). Furthermore, the style in which questions are presented to participants also affects the degree of trustworthiness. Questions should be phased in a way that does not lead or encourage participants to provide a particular response (McKinnon, 1988). The use of interview notes, audio

recordings and interview guides that helped ensure all questions were neutrally phrased and minimise influencing participant's responses, and as a result contributed to achieving trustworthy and reliable qualitative data. The interview guide and methods of analysis are discussed in Chapter 5.8.3.

4.6.2 Validity

Validity can be defined as the extent to which a concept is accurately measured (Heale and Twycross, 2015). In most cases, validity refers to whether the conclusions of a study reflect what the data and results depict (Bryman, 2012). Although validity can be measured, researchers must remember that validity is relative to the context of the research and therefore is not absolute (Kaplan *et al.*, 1976). Concerning quantitative research, validity can be split into two main areas - internal and external (Winter, 2000). Internal validity can be measured via three entities; content, construct, and criterion (Bryman, 2012; Creswell and Plano Clark, 2011; Heale and Twycross, 2015).

The first category, content validity, addresses the items or questions within a data collection tool and their representation of the research question - it measures how much of the research phenomena the instrument covers (Creswell and Plano Clark, 2011; Heale and Twycross, 2015). Precautions can be made to maintain content validity by conducting pilot studies, having instruments reviewed by expert panels or using previously validated tools. The components used in the quantitative elements of this research were adapted from previously validated and well-established instruments and are discussed in more detail in the methods chapter 5.8.1.

Criterion validity measures the correlation between a newly created instrument and an established instrument that measures the same variable of interest. A strong relationship between the scores from each instrument implies that criterion validity is present (Heale and Twycross, 2015; Kaplan *et al.*, 1976). Criterion validity was also found in the pre- and post-knowledge-based quizzes as these questions have been taken and adapted from past public examination papers. Construct validity pertains to researchers demonstrating that their data collection tools accurately measure what they intend to measure. This type of validity can be achieved through conducting multiple studies focusing on the same phenomena and their correlation to theories and hypotheses or by using instruments related to the measured construct with evidence of reliable and valid data (Shadish *et al.*, 2002; Yilmaz, 2013). This study incorporated construct validity as the questionnaire data collection tool discussed in chapter 5.8.1 included pre-validated scales designed to measure self-reported intrinsic motivation. It also contained criterion validity as the scales used in both the pre- and post-questionnaire have been used in published literature to measure changes in motivation as a result of using AR educational tools.

External validity is the extent to which casual relationships in a particular sample can be generalised across a wider population (Shadish *et al.*, 2002). The degree of rigour in external validity considers the sample size, sampling framework, and inferential statistics adopted. The following methods chapter discusses these components in greater depth (Chapters 5.4 and 5.8).

Similar to reliability, validity in qualitative research is more ambiguous due to the nature of the data generated. Qualitative researchers often purport that validity cannot be measured

with a standardised test, but rather validity is dependent on a researcher's beliefs as to what areas of their research need validation (Winter, 2000). Those with this perspective may view validity as referring only to instruments, measurements, observations, scores, relationships between scores, or observable variations rather than the process as a whole (Winter, 2000). Maxwell (1992) identified typologies of validity within qualitative research that are tied to different stages of the research process – descriptive validity, interpretative validity and theoretical validity.

Descriptive validity is the degree to which a researcher accurately reported and documented what they observed. This definition also included the accuracy of the deductions generated from a researcher's data (Maxwell, 1992; Winter, 2000). The foundation of observation and description is based on theory; therefore, descriptive validity also depends on theory (Maxwell, 1992). Descriptive validity is threatened when two observers describe different accounts of the same situation. Therefore, when two researchers agree on their observations, validity is strengthened, increasing the likelihood of credible findings (Johnson and Christensen, 2017). A simple yet effective way to ensure a minimal discrepancy between accounts of a situation is to have audio or visual recordings that can be referred to should there be any confusion. With respect to this piece of research, digital audio recordings were made for each interview which were then sent to be professionally transcribed. As mentioned in section 4.6.1, the transcriptions were cross-referenced with the audio recording to ensure each interview had accurately been transcribed. The following methods chapter discusses the format of the interviews in greater detail.

Maxwell described interpretative validity as providing an accurate description of the people, observations and events that occur during the study but also added that it related to the accuracy of meanings behind those descriptions (Maxwell, 1992). Therefore, interpretative validity relates to the accuracy with which a researcher precisely reports the meaning behind each code in qualitative data analysis (Johnson and Christensen, 2017). Maxwell further elaborated, highlighting that interpretive validity is grounded in the personal accounts of participants and the language they use to provide meaning (Maxwell, 1992). Johnson & Christensen (2017) described this phenomenon as the emic perspective, where the researcher attempts to "get inside the heads of participants" in order to "see and feel" what they experience. Qualitative data gathered from questionnaires and video call interviews were screened, coded and then reviewed with the supervisory team to foster a high level of interpretative validity. Additionally, this study adopted another method to ensure interpretative validity whereby comments and perspectives shared in the open-ended questions in the questionnaires were discussed during the video call interviews with student and tutor participants. By doing this, the lead researcher attempted to ensure they understood the perspectives shared in the questionnaires correctly.

The third category, theoretical validity, centres on the degree to which a researcher accurately makes a theoretical explanation consistent with their results (Johnson and Christensen, 2017; Maxwell, 1992). There are two elements to the theory, the first is the explanation of concepts, and the second is the relationships predicted to exist between the concepts (Maxwell, 1992). Hence, as a theory develops, it moves away from being a series of facts and becomes an explanation of the phenomenon. The generated theory is less focused on interpreting and describing each participant's experiences but centres on an

abstract perspective (Johnson and Christensen, 2017). An example of this type of validity would be a researcher immersed in observing participants in their environment for a prolonged period. However, this study did not adopt this form of validity as it would be almost impossible for the lead researcher to closely observe each participant as they were based at a number of different school sites in several different locations, all using the intervention tool simultaneously over a prolonged period. Although, this example of theoretical validity was not employed, the use of the Normalisation Process Theory to construct interview questions and analyse participants responses (chapter 5.7.3) falls into this domain of validity – the framework helps researchers to identify stable patterns of behaviour such that the generated theory falls in-line with the measured construct.

As mentioned in section 4.3.1, the results and conclusions drawn from qualitative studies are not intended to be generalised across a wider population. However, the findings and concepts generated from such studies offer some degree of transferability (Bryman, 2012; Lincoln and Guba, 1985). Transferability can be achieved by gathering rich and dense sets of data from each individual from a large sample size of participants to reach data saturation (Chapter 5.4.2) (Geertz, 1973).

Mixed methods research possesses the ability to overcome the limitations associated with either quantitative or qualitative methods and, at the same time, synergise their strengths. Similarly, mixed methods research also addresses limits to the validity and reliability of both qualitative and quantitative research. Triangulating the results of mixed methods studies can increase content, construct, and criterion validity and the analysis's external validity and trustworthiness. This balance occurs due to a more holistic perspective on the research

topic, ultimately compensating for the typical weakness of either method when used individually (Gorard and Taylor, 2004).

4.6.3 Reflexivity

The literature surrounding the quality and rigour of research, particularly qualitative research, has acknowledged the importance of reflexivity (Jootun *et al.*, 2009; Lambert *et al.*, 2010; McCabe and Holmes, 2009). The term depicts the ongoing self-reflection process that a researcher engages in to acknowledge their actions, feelings and perceptions' effect on the construction of their work (Darawsheh, 2014; Parahoo, 2006). Reflexivity is heavily associated with qualitative research and is considered a pillar of 'critical' qualitative research (Fontana, 2004). The addition of a reflexive process increases the transparency of the researcher's subjectivity towards their research design, data collection methods, data analysis and interpretation procedures, and it's likely impact on the construction of the findings (Pope and Mays, 1995). This offers opportunities for researchers to articulate and report the likely impact they have had on the construction of their findings and measure the credibility of their conclusions. Readers would then be able to judge the potential for transferability of the study's findings in similar populations (Finlay and Ballinger, 2006; Gilgun, 2006).

The use of reflexivity within quantitative research is rare due to the philosophical nature of quantitative research methods (section 4.3.1). Furthermore, an integral component of quantitative research is to minimise the risk of bias. Indeed, Ryan and Golden (2006) highlighted that using reflexivity in quantitative research could be seen as a weakness as it might undermine the underpinning control measures of quantitative research's validity.

The socially contingent nature of the qualitative data generated from the questionnaires and interviews meant that reflexivity would be an integral component to improve the credibility of this doctoral research study (Finlay and Ballinger, 2006; Gilgun, 2006). The assumption that all the qualitative data gathered was factually correct could not be made as the participants' perspectives are subjective and of a socially contingent nature. The subjective nature of the data resulted from many factors that included the beliefs of the lead researcher, sampling and recruitment methods, data collection methods, and the individual beliefs of the participants at that particular time of data collection (Braun and Clarke, 2013). Some of the quantitative data collected from the questionnaires were also socially contingent. Likert type and Likert scale questions generated subjective data as the anchor points on the scale represented the level to which participants agreed with each statement. The remaining quantitative data from the pre- and post-intervention assessments generated statistical data that was naturally objective.

Researchers' understanding of the importance of reflexivity in their research approach can encourage the discussion of unexpected or alternate findings (Bryman, 2006). Due to this possibility, a reflexive approach was adopted and field notes were kept from the beginning of this study up until the completion of this thesis.

4.7 Chapter Summary

This chapter has discussed the methodological considerations surrounding the design of this study and presented the reasoning pertaining to the decision to adopt a mixed methods approach. A mixed methods approach permitted a greater depth of detail to be obtained

from the data collection tools so that the research question, aims and objectives could be answered as extensively as possible. Choosing a qualitative or quantitative approach alone would render this thesis vulnerable to questioning its context or statistical significance. The little existing research surrounding AR educational tools in sixth form biology and chemistry education, as well as undergraduate pharmacy education, meant that a mixed method design study was extremely appropriate.

The pragmatic nature of mixed methods combined the benefits of both quantitative and qualitative research and, at the same time, negated many of the shortcomings a quantitative or qualitative approach alone may have brought. A greater depth of detail and context can be uncovered from participants through qualitative data collection elements, and at the same time, quantitative data provides standardisation. The findings generated from the one group pre- and post-intervention quizzes that determined the effectiveness of the AR educational tool can be generalised across a broader population. In contrast, participants' perspectives and opinions on the educational tool and their motivation towards learning were gathered from the pre- and post-questionnaires and Interviews. Findings from all data collection methods were then triangulated and used to reinforce one another to provide context to the magnitude of the effect and increase the study's rigour. The importance of reflexivity and its relation to the socially contingent data gathered has also been discussed. Detailed discussions of this research programme’s aims and objectives, data collection methods and analysis tools can be found in the following Methods chapter.

5 Methods

5.1 Introduction

This chapter examines the specific methods that were used in this programme of research. It begins by discussing the study's design explored in section 5.2, followed by its ethical approval in section 5.3. The sampling and recruitment of participants are discussed in sections 5.4 and 5.5, respectively. Section 5.6 discusses the use of Google Drive and its role in the data collection tools. A description of the intervention tool can be found in section 5.7. Section 5.8 explores the data collection tools used in the study, followed by the associated analysis techniques (section 5.9). Data protection and confidentiality are discussed in section 5.10, followed by the chapter summary in section 5.11.

5.2 Study Design

This study evaluated the effectiveness of the AR Pharma Compounds tool in the education of sixth form and undergraduate students. Each group of students were exposed to the same study format. This included study design, series of activities and study protocol.

Sixth form students who participated in the study were year 12 biology and chemistry sixth form/college students who were educated in the United Kingdom (UK) or Kenya – one private sixth form school in the UK, and two private sixth form schools in Kenya. Prior to the COVID-19 pandemic, three additional sixth form schools and colleges had intended to participate in the study – two public colleges from the UK and one private school in Hong Kong). Unfortunately, those institutions did not participate beyond their initial intention to be involved due to the COVID-19 pandemic.

Sixth Form schools and colleges not situated in the UK were international schools whose academic programmes were based on the British National Curriculum. Therefore, those sixth forms and colleges delivered A-level biology and chemistry courses equivalent to and entered into examinations that are the same or equivalent to those taken by students from the UK (Brookhouse, 2021; St Austin's Academy, 2021). The undergraduate students who also participated in this study were enrolled as stage 2 MPharm students at a School of pharmacy in the UK.

The study adopted a mixed methods approach involving pre- and post-questionnaires, pre- and post-knowledge-based quizzes, and one-on-one semi-structured video call interviews (figure 5.1). This format allowed for a direct comparison between attitudes and motivations towards learning as well as any changes in knowledge both before and after the intervention was introduced (Aw *et al.*, 2020; Gan *et al.*, 2018; Hou and Lin, 2017; Schneider *et al.*, 2020; Wong *et al.*, 2020). The intervention period lasted for a minimum of three months, from participants receiving the Pharma Compound AR tool to when participants were invited to complete the post-knowledge-based quiz and post-questionnaire. Previous literature that investigated AR educational tools in academic education had relatively short intervention periods; most would introduce the technology to participants and proceed to collect post-responses all within the same teaching session or directly after the AR tools introduction (Aw *et al.*, 2020; Gan *et al.*, 2018; Hou and Lin, 2017; Schneider *et al.*, 2020). As a result, this study was designed to investigate the effects on students' attitudes, motivation towards learning and changes in knowledge after prolonged exposure to the AR educational tool. Over the intervention period, participants could use the AR tool as often

as they desired in any scenario, i.e. in class, at home, for revision, in individual or group learning sessions.

Both sixth form and undergraduate participants were first invited to complete a pre-questionnaire and a pre-knowledge-based quiz. Both forms were web-based and hosted on Google Drive's "Forms" platform. The pre-questionnaire focused on participants' current learning and revision habits, self-reported motivation towards learning with their current learning methods, and their perception of AR at the time. The pre-knowledge-based quiz completed by sixth form students was based on teaching material that would have been delivered during year 12 biology and chemistry courses. Similarly, the pre-knowledge-based quiz completed by undergraduate MPharm students contained similar content derived from material delivered at stage 2 of the course (Chapter 6.9.2). A large proportion of the content in the stage 2 quizzes was the same as in the sixth form quizzes. This is because the concepts and phenomena encountered at stage 2 of the MPharm course are similar to or based on those encountered in biology and chemistry A-level courses but more complex.

Once participants had completed the pre-questionnaire and pre-knowledge-based quiz, they were then given access AR Pharma Compounds tool (the Pharma Compounds mobile app and the associated target image cards) to use as a learning aid and revision tool (Appendix 1). Participants were invited to complete the post-questionnaire and post-quiz after the intervention period. The post-elements of the study closely resembled the pre-intervention period elements. The post-questionnaire focused on the views and perspectives of participants on the AR intervention as well as their motivation towards learning when using the AR system. Concerning the post-quiz, the underpinning concepts

examined, format and style of the questions were identical to that of the pre-quiz; however, the specific subject of the question was altered such that participants would not answer the post-quiz from their memory of the pre-quiz - e.g. The pre-quiz question may have asked a question in relation to the bonds formed between a glucose and galactose molecules. In contrast, the post-quiz would ask the same question in relation to glucose and fructose molecules. The underpinning principle is the same but is applied to an equally challenging scenario. The similarities in the pre- and post-questionnaires and quizzes allowed individual participant responses to be directly compared. The final phase of the study involved participants and tutors participating in a one-on-one video call semi-structured interviews to further discuss the views and perspectives shared in the pre- and post-questionnaires (chapter 10). Tutors were asked to share their perspectives on the themes identified from student participants' comments. The interviews also explored possible ways the Pharma Compounds AR educational tool could be normalised into learning environments. Figure 5.1 displays the order of this research programme. Figure 5.2 depicts the timeline of data collection events as described above in this section. The figure also includes the data collection events that contributed to the development of the Pharma Compounds educational AR tool (Chapter 6).

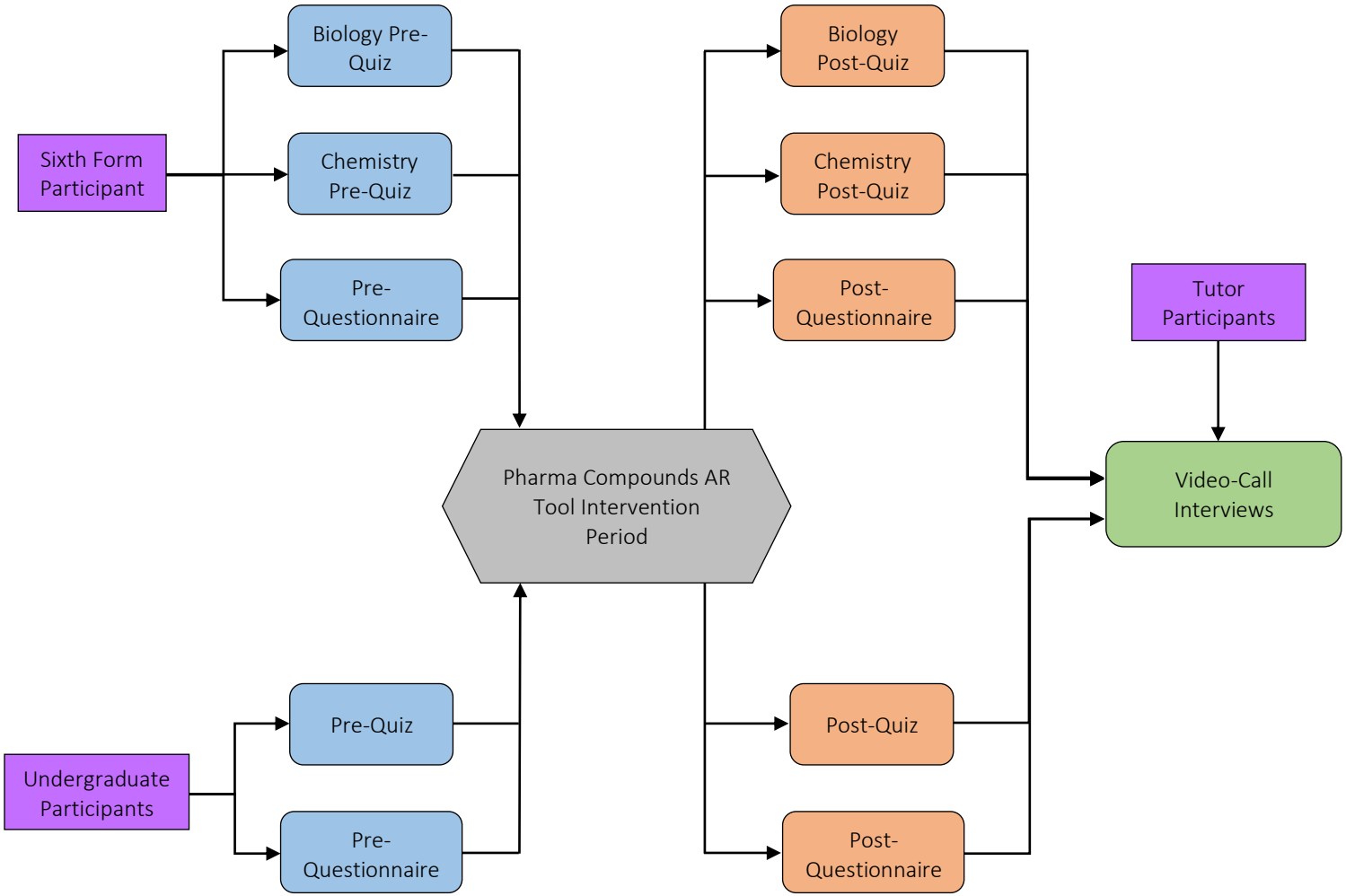


Figure 5.1 Programme of work for this study. It details the progression of the sixth form and undergraduate participants through the pre- and post-intervention elements. Qualitative and quantitative data were collected simultaneously and sequentially in a pre- and post-structure using MCQs, questionnaires and video call interviews. *Students were enrolled in biology and chemistry courses, so they completed biology and chemistry quizzes.

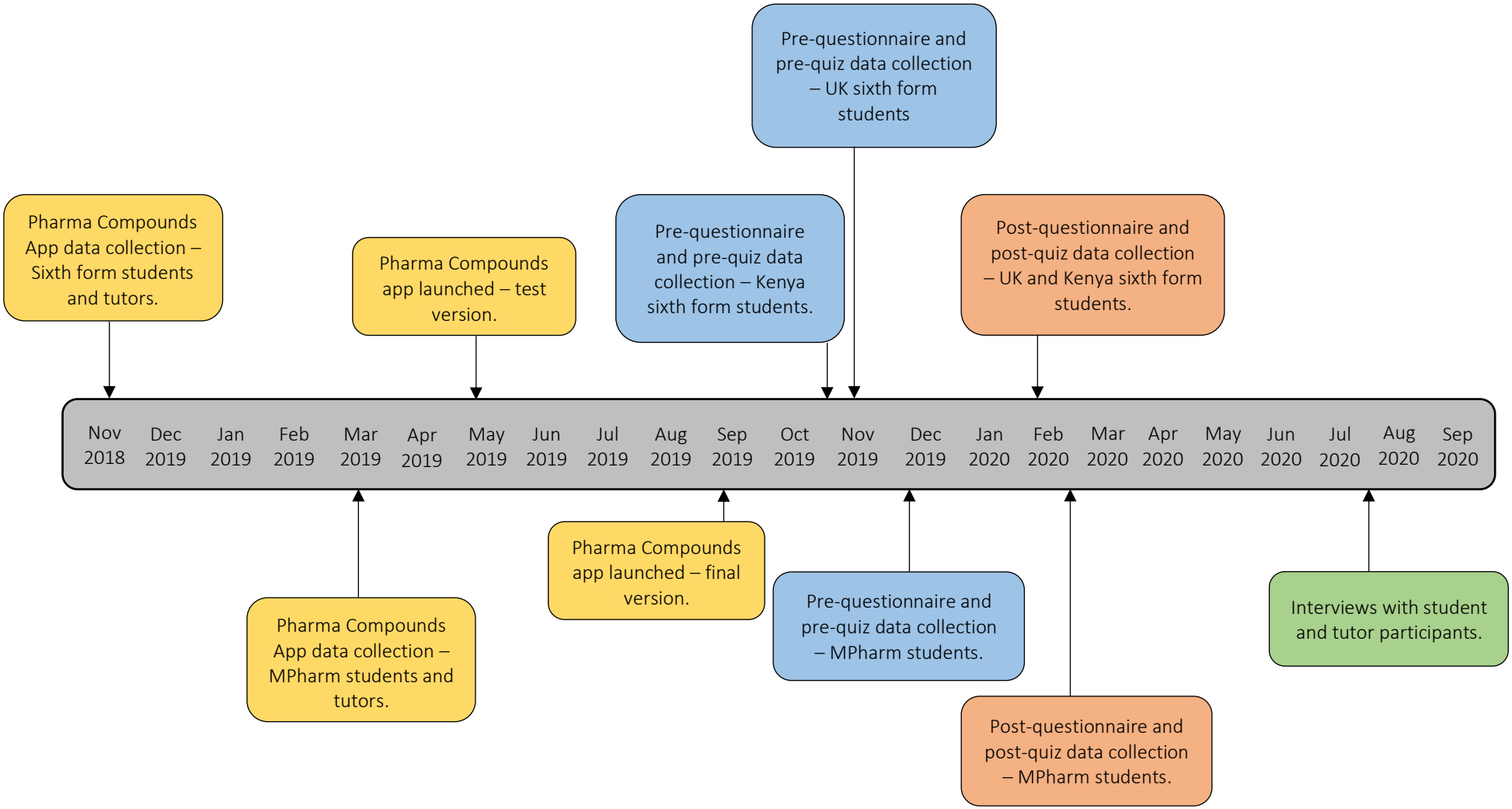


Figure 5.2 Timeline of data collection during this programme of research (includes data collection for the Pharma Compounds App development).

5.3 Ethical Approval

The first ethical application related to developing the Pharma Compound AR intervention tool (Appendix 1). The development of the AR tool is detailed in Chapter 6. The relevant letters of invitation (Appendices 3, 4 and 5), participant information sheets (Appendices 6, 7, 8, 9 and 10), consent forms (Appendices 11, 12, 13 and 14), and questionnaires (Appendices 15, 16, 17 and 18) associated with the intervention tool development accompanied this application. The following ethical applications (and amendments) related to the evaluation of the AR Pharma Compounds tool and involved the participation of sixth form biology and chemistry students (Appendix 19), undergraduate MPharm students (Appendix 20) and the respective tutors (Appendix 21). Again, all relevant documents associated with the study accompanied the applications; Letters of invitation (Appendices 22 and 23), participant information sheets (Appendices 24, 25, 26, 27, 28 29 and 30), consent forms (Appendices 31, 32, 33, 34 and 35), questionnaires (Appendices 36, 37, 38 and 39), quizzes (Appendices 40, 41, 42 and 43), and interview questions and protocols (Appendix 44). Favourable ethical opinions were obtained for all applications made.

5.4 Sampling

5.4.1 Sampling for Quantitative Data Collection (Questionnaires and Knowledge quizzes)

The sample sizes for the quantitative elements of this study were calculated using G*Power 3.1 (Faul *et al.*, 2009). This programme uses effect size, probability value (p-value), and power to calculate the minimum number of participants required to reach significance in a given statistical test.

Effect size has been defined as how a researcher can identify the practical strength of their conclusions regarding differences or relationships among groups and variables in a quantitative study (Creswell and Plano Clark, 2011) – in relation to this study, the effect size would indicate how promising the Pharma Compounds AR tool is improving a learners knowledge and their motivation towards learning. The effect size is usually adjusted by the researcher to account for the degree of expected effect (Cohen, 1988). An effect size of 0.2 is considered to be of small magnitude, 0.5 as medium and 0.8 as large. As the literature had failed to document the effect size used in similar studies that involved AR in education, the effect size of 0.5 (medium) and 0.8 (large) were both used to calculate appropriate sample sizes (Maryam Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Salem *et al.*, 2020; Sanii, 2020; Sari *et al.*, 2021; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020; Yang *et al.*, 2018; Yapici and Karakoyun, 2021). This effect size has been reported to be a suitable value as it was unknown the degree to which the intervention tool would affect participants' education (Cohen, 1988).

Statistical analysis is associated with two types of errors, type I (α) and type II (β).

A type I error is signified by a probability value and is said to occur when the null hypothesis is incorrectly rejected, meaning there is no significant difference between two groups and the statement is true. Typically researchers adopt a probability value of 0.05, which signifies there is a 5% chance that any differences observed result from chance rather than the intervention. (Banerjee *et al.*, 2009; Jones *et al.*, 2003).

On the other hand, Type II errors relate to power and occur when the null hypothesis is accepted incorrectly (the null hypothesis statements are false, and there are significant differences) (Banerjee *et al.*, 2009; Jones *et al.*, 2003; Underwood and Chapman, 2003). Power refers to the probability of observing an effect in the sample group of a specified effect size or greater that can be found in a wider population (1-β). The minimum probability of a type II error is set to an industry standard of 0.20, with many studies opting to use this value (Banerjee *et al.*, 2009). With a type II error given as 0.20, power was calculated as 0.80.

To calculate the sample size for this programme of research an effect size of 0.5 and 0.8 were used in conjunction with a power value of 0.8. The p-value was set to 0.05 for statistical significance and the rejection of the null hypotheses below (Cohen, 1988);

- There is no significant difference in self-reported motivation towards learning after using the AR Pharma Compounds tool
- There is no significant difference in the knowledge-based quiz scores after the use of the AR Pharma Compounds tool

With the effect size set to 0.5, a sample size of 34 was calculated to identify statistical significance in a two-tailed dependent t-test performed concerning the effect of the intervention on individual students' mean motivation and mean usefulness towards learning, as well as changes in the mean knowledge-based quiz scores. Adjusting the effect size to 0.8, a sample size of 15 was calculated as the necessary number of participants for each student group (sixth form or undergraduate) to establish significant differences in a

two tailed t-test. In addition, concerning the Wilcoxon sign-rank test to compare individual Intrinsic Motivation Inventory (IMI) Likert statements, a sample size of 35 was needed to identify statistical significance when the effect size was set to 0.5 (sections 5.8.1 and 5.8.2). When adjusted to 0.8, a sample size of 15 was necessary to identify statistical significance.

As mentioned above, published literature had not readily reported the effect sized used in their bodies of work, therefore a medium effect size (0.5) was used to calculate the sample size for both the two-sided t-test and the Wilcoxon sign-rank test. Finally, the calculated sample size was adjusted to account for potential participant drop out at a rate of 20%, resulting in an adjusted sample size of 43 (Bell et al., 2013) - This dropout rate had been reported in literature that examined the participant dropout rate of 71 RCTs.

5.4.2 Sampling for Video Call Interviews

Participants who had completed the pre- and post-questionnaire or the pre- and post-knowledge-based quizzes were invited to participate in the one-on-one video call interviews. In addition, tutors involved in year 12 biology or chemistry education or stage two MPharm education were invited to participate in the interviews.

Sixth form students recruited to participate in the one-on-one video call interviews were based in the UK or Kenya, whereas undergraduate students were all enrolled in a university within the UK (international MPharm students may have been at home in their respective countries due to the COVID-19 pandemic). Tutors of participants were also recruited to participate, and they, too were either based in the UK or Kenya. As mentioned in Chapter 4.5.3 and further detailed in Chapter 11.5, the COVID-19 pandemic had a significant impact

on the continued participation of students as the study progressed. As a result of reduced participant numbers towards the end stages of the study (Chapter 10.2), a purposive sampling strategy was adopted (Etikan *et al.*, 2016). Participants who had completed both pre- and post-questionnaires or both pre- and post-knowledge-based quizzes were recruited to participate, together with tutors involved in delivering sixth form year 12 biology and chemistry material or undergraduate stage 2 MPharm material.

With respect to sample sizes in qualitative research, there is no specific guidance or approved method to calculate the minimum required number of participants. There is, however, a point of data saturation. The point of saturation is reached when no new themes and ideas emerge from the data (Bowen, 2008; Guest *et al.*, 2006). Inconsistencies in the reporting and evidence of data saturation in qualitative research have caused great controversy in determining guidelines for sample sizes in qualitative research (Bowen, 2008; Onwuegbuzie and Leech, 2005). The definition of data saturation implies that a single set of data from one interview may not be sufficient. The point of saturation can only be known after two or more data sets are obtained and examined. Although small sample sizes may be sufficient to provide deep and nuanced findings, they may not enable the researcher to identify when data saturation has been reached (Bobby, 2016). It is also important to note that researchers can unknowingly reach data saturation from the first piece of data collected.

On the other hand, large sample sizes often prevent researchers from conducting deep, case-by-case analyses required for quality qualitative research (Sandelowski, 1995). With no official guidelines to test for the adequacy of a sample size required to reach data

saturation, researchers have highlighted factors that must be considered to reach saturation; type of research, the research question, data collection method and frequency of data collection (Malterud *et al.*, 2016; Sandelowski, 1995).

In this study, participants were recruited and interviewed by the lead researchers until interim analysis of the data suggested that the broad topics of interest were likely to have reached saturation on the basis of no new points having been made in at least two preceding interviews. At this point, two more interviews were conducted to ensure that no new concepts related to the broad themes emerged.

All participants interviewed were asked to explain their responses further when necessary to cover as many topic areas and gather as much data as possible. The literature surrounding the use of AR educational tools in sixth form biology and chemistry and pharmacy HE that utilised interviews did not report the number of interviews conducted - a pilot study included in this thesis' literature review reported two interview participants (Wozniak *et al.*, 2020) (Chapter 2.5.1).

5.5 Recruitment

Year 12 biology and chemistry students were recruited from sixth form schools and colleges in the UK and Kenya (section 5.2). These sixth form institutions were selected as they had an existing relationship with the Keele University School of Pharmacy and Bioengineering. Recruitment was extended to other sixth form institutions with no relationship to Keele University; however, they did not agree to participate. The lead supervisor made initial contact with representatives from the sixth form schools and colleges via email, introducing

themself and the study's premise during the 2017/2018 academic year. Once initial contact had been made, schools were provided with greater detail via email, highlighting what potential participants were required to do and complete should they be involved in the study. Once the sixth form schools and colleges had agreed to be involved, individual students were recruited via cohort emails (Appendix 3, 4 and 5). As the lead researcher initially did not have access to student email addresses, the recruitment email was first sent to a gatekeeper of the participating colleges, who then forwarded the email to potential Year 12 Biology and Chemistry participants (Patterson *et al.*, 2011). The recruitment email contained an invitation letter (Appendix 22), a participant information sheet detailing the features of the study (Appendix 24), an information sheet for parents/guardians of the students (Appendix 25), a consent form (Appendix 31) and the lead researchers contact details.

Undergraduate stage 2 MPharm students were recruited from the Pharmacy MPharm course by potential participants being first approached during a teaching session, and being briefly introduced to the research project and its scope. Next, potential participants were informed of a cohort email they would receive following the brief talk from a gatekeeper on behalf of the lead researcher. The email contained an invitation letter that introduced the research topic (Appendix 23), a participant information sheet detailing what they would be required to do (Appendix 26), a consent form (Appendix 32) and the lead researcher's contact details should they have any questions or queries relating to the research.

Tutors invited to participate in the interviews were recruited from the same institutions as the students who participated, provided they were involved in the delivery of year 12 sixth

form biology or chemistry course material or stage 2 MPharm course material. These participants were initially contacted directly via email, which contained an invitation letter that introduced the research topic, an online participant information sheet detailing what they would be required to do (Appendix 30), an online consent form (Appendix 35) and the lead researchers contact details should they have any questions or queries relating to the research. If tutor participants had not already used the Pharma Compound AR tool, they were sent a copy of the cards and instructions on how to download and use the app.

Reminder emails were sent at regular intervals after each initial invitational email for each stage of the data collection process Figure 5.2. As mentioned above, gatekeepers for sixth-form and undergraduate students were sent the initial recruitment email to distribute to student cohorts. They were then sent additional emails to forwards on to student participants weekly for three weeks in attempt to recruit as many participants as possible. With respect to the post-intervention elements of the data collection process, reminder emails were sent out directly to student participants, via the email they provided in the pre-intervention elements, reminding them to complete and submit the post-intervention quiz and questionnaire. These reminders were also sent weekly during a three-week period after the initial post-intervention email.

5.6 Google Drive

This study utilised the 'Forms' capabilities of the online Google Drive platform. Participant information sheets, consent forms, questionnaires, and knowledge-based quizzes were all created using the Forms application on Google drive. The Google Drive platform securely encrypts data while in transit and in storage that only the creator of the Forms (lead

researcher) has access to. With participants from two countries, the ability to instantaneously send documents using an online platform streamlined the project. Consent forms were sent out to all participants, where they were required to check the 'Yes' boxes signifying their understanding of the statements before they could continue. These online documents and forms included all the required elements that would otherwise be necessary for physical hard copies of consent forms, and typing one's name signified an electronic signature on the form. Participants were asked to provide their full name and a private email for correspondence between themselves and the lead researcher. The following stages of the study also employed the Google Forms application on Google drive. The pre-questionnaire completed by both sixth form and undergraduate students automatically followed the completion of the consent form. Participants could not proceed to the pre-questionnaire until they had provided consent. The web link to the pre-quiz was also included in the same email to be completed after submitting the consent form and pre-questionnaire. Concerning the post-questionnaire and post-quiz, links to both Google Drive Forms were sent after the intervention period had ended to the email address participants provided earlier. Each Google Form used in the studies collected participants' responses immediately at the point of submitting responses. Each data entry field was set to require a response before participants could proceed or submit.

5.7 Data Collection

5.7.1 Pre- and Post-Questionnaires

The aim of the pre- and post-questionnaires was to gather a uniform measure of participants' views, opinions, and self-reported intrinsic motivation towards learning using; their conventional methods of learning, and then with the addition of the AR Pharma

Compound tool (Appendix 1). Likert scale and Likert type questions afforded comparisons between responses before and after using the intervention tool. Open-ended questions were used in both the pre- and post-questionnaires to gain a more contextual understanding of the Likert type and Likert scale responses and participants' experiences while using the Pharma Compound tool.

Evaluative questionnaires are a proven and well-established data collection tool that can be used when gathering participant thoughts on an educational learning tool, particularly within healthcare and the science fields (Barrett, 2006; Gallagher *et al.*, 2013; Kaveevivitchai *et al.*, 2009; Lin *et al.*, 2015). Likert scales and Likert type questions have been widely used in data collection tools to measure attitudes and provide additional context to qualitative data (Hodge and Gillespie, 2003). The former consists of a series of statements or items that explore different dimensions of a subject to which participants select their level of agreement on an ordinal scale (typically a five or seven-point scale) (Joshi *et al.*, 2015). The latter refers to individual statements of the same description that are not grouped to form a scale (i.e., a stand-alone statement with Likert anchor points). Researchers commonly use Likert scales when measuring less concrete concepts difficult to quantify, such as motivation, satisfaction and confidence (Rickards *et al.*, 2012). Likert scales and Likert type questions play a prominent role when assessing self-reported intrinsic motivation (Beeland, 2006; Calvo-Ferrer, 2017; Chang and Yu, 2017; Perry, 2015; Pinto-Llorente *et al.*, 2017; Salem *et al.*, 2020; Torff and Tirotta, 2010). As a result of the limited publications that surrounded the use of an AR educational tool in biology, chemistry and pharmacy HE, there were very few validated tools that holistically evaluated AR interventions – several publications focused on the development and the evaluation of the educational tools'

useability rather than its direct effect on education (Maryam Abdinejad *et al.*, 2021; Reeves *et al.*, 2021; Safadel and White, 2019; Wozniak *et al.*, 2020; Yapici and Karakoyun, 2021).

Creating questions for an evaluative questionnaire can be a time and resource-intensive process requiring several factors to be considered (Leung, 2001). Although the type of many questions were pre-determined by validated instruments, particular attention was paid to their order and the type of additional included questions. Focusing on these characteristics of the questionnaires contributed to their ability to gather detailed insights into participants' views and simultaneously prevent the survey from being too time-consuming to complete (Cohen *et al.*, 2007). The majority of questions used in the pre- and post-questionnaires were adapted from the published literature that had been used to measure self-reported intrinsic motivation and usefulness of an AR and non-AR intervention or activity (Choi *et al.*, 2009; Hanafi *et al.*, 2017; Monteiro *et al.*, 2015; Nieuwhof-Leppink *et al.*, 2019; Watson and Livingstone, 2018). The pre- and post-questionnaires included Likert scales that recorded self-reported motivation and usefulness when participants used their conventional learning methods and the AR intervention tool. Questions were taken and adapted from the original IMI multidimensional self-reporting tool (McAuley *et al.*, 1989; Ryan, 1982) - either their conventional learning methods (pre-questionnaire) or the Pharma Compounds system (post-questionnaire) were the subject of each Likert statement. The IMI has been included in published literature that assessed participants' subjective motivation and experiences related to a target activity such as laboratory tasks, sports, school and medical procedures (Bryce *et al.*, 2018; Choi *et al.*, 2009; Markland and Hardy, 1997; McAuley *et al.*, 1989; Monteiro *et al.*, 2015; Nieuwhof-Leppink *et al.*, 2019; Plant and Ryan, 1985; Takeda *et al.*, 2017; Williams *et al.*, 1998). The IMI consists of six Likert-type subscales

with 56 items that measure experiences of interest/enjoyment, effort, value/usefulness, pressure/tension, relatedness, and perceived choice. It was developed to support the strongly validated self-determined theory that detailed motivation is controlled autonomy, belonging and competence (Ryan, 1982; Ryan and Deci, 2004, 2000). In relation to education, the theory explains that students who demonstrated application towards a task often went on to internalise the task and excel (Ostrow and Heffernan, 2018).

Quantitative data collected from this research was partly derived from Likert scale and Likert type questions. The questions derived from the IMI consisted of 7-point Likert scales where participants were asked to rank their agreement with the associated statement from 1 (not true at all) to 7 (very true). The IMI did not specify the need to use a 7-point scale; however, literature that reported to have used the IMI scale employed the 7-point scale and as a result, 7-anchor points were also used in this studies questionnaires (Jones and Skaggs, 2016; Mekler *et al.*, 2017; Plant and Ryan, 1985; Ryan, 1982). Additional Likert-type questions (separate from the IMI adapted questions) employed a 5-point scale; 5-point Likert scale ranges are commonly found in primary research studies and have been shown to comprehensively enable respondents to express their views and be less confusing to complete helping to improve response rate (Babakus and Mangold, 1992; Bertram, 2007; Marton-Williams, 1986). As such, the five-point scales were also used in the pre-and post-questionnaires. Both the 5 and 7-point scales afford for participants to select a middle anchor point. The inclusion of a mid-point has been debated in the literature , with some researchers suggesting that the relationship between one item and the next could be affected by the inclusion of a mid-point (Garland, 1991; Nadler *et al.*, 2015). Garland (1991) explained that by removing the mid-point, researchers could minimise the social desirability

bias expressed by participants. Conversely, the greatest argument in support of including a mid-point is that in its absence, respondents are forced to choose one side or the other when in fact, their personal position may be neutral; as a result, this effect will increase the level of error within the survey (Converse, 1970). For this reason, it was decided to include a mid-point to not force the participant's hand in expressing their opinions concerning the Likert items and scales.

The pre-intervention questionnaires also contained demographic questions that gathered data relating to participant age, gender, type of student, subject taught etc., to ascertain cohort characteristics and investigate if the AR tool had different effects on knowledge in different group characteristics. The Likert scale questions adapted from the IMI used in pre- and post-intervention questionnaires were the interest/enjoyment and the value and usefulness subscales (14 items). The interest/enjoyment scale was determined to be the main indicator of motivation towards the subject of the Likert statements (Choi *et al.*, 2009; Markland and Hardy, 1997; Monteiro *et al.*, 2015). The pre-questionnaires also included seven additional 5-point Likert style questions to ascertain student perceptions of mobile technology and its use in an educational setting and students' perceived motivation towards learning in several different styled teaching sessions. These questions were developed by the lead researcher and reviewed by the supervisory team. Both pre- and post-questionnaires also included open-ended questions to allow participants to share their views regarding their general learning and motivation towards learning in their own words and provide context to some of their Likert responses. The post-questionnaire also included open-ended questions to explore the advantages and disadvantages of using the AR educational tool and potential improvements to the system. The supervisory team reviewed

the questions used in all surveys to strengthen the validity of the data collection tools, as discussed in chapter 4.6.2.

Both the pre- and post-questionnaires were created utilising the Google Forms function on Google Drive (section 5.6). Every question, including free text, was made compulsory to answer and would not allow respondents to proceed without answering the questionnaires completely. This function ensured that every submitted survey was 100% complete without missing data. However, this function of Google forms may have reduced the reliability of the responses to the questions as participants may have provided arbitrary responses just so they could progress and submit the online form (Brehm, 1966; Ganassali, 2008; Stieger *et al.*, 2007; Tian and Tang, 2013). The form also required participants to provide an email address to pair their pre- and post-intervention questionnaire submissions.

5.7.2 Pre- and Post-Knowledge based Quizzes

Part of the quantitative data collected from this study was obtained through pre- and post-intervention knowledge-based quizzes. Quizzes were hosted on the online Google Drive "Forms" platform, accessed by students via a weblink included in an email (Section 5.6). Once participants had completed and submitted their online quizzes, the data was automatically collected and stored on the password-protected Google Drive Forms platform for analysis. Both pre- and post-knowledge-based quizzes answered by participants consisted of multiple-choice questions (MCQs). As mentioned in section 5.2, the style and format of questions in the pre-quiz were identical to the style and format of the post-quiz questions. Each MCQ had five options to select from and was formatted so that only one option could be submitted as an answer. The examined concepts of the pre-quiz were

identical to those in the post-quiz; however, the subject and the answers to the quiz question were changed such that participants would not be inclined to provide the same response on the post-quiz as they did in the pre-quiz. A limitation of using the same or very similar quiz pre- and post-quiz is the sensitisation of participants to the limited material contained in the quiz (Stratton, 2019). However, Literature has suggested that this pre- and post- format is an effective method of monitoring any changes in knowledge resulting from the use of an educational intervention (Akçayır *et al.*, 2016; D. Campbell and Stanley, 1963; Davis *et al.*, 2000; Detroyer *et al.*, 2016; Gallagher *et al.*, 2013; Wilkes and Bligh, 1999).

Before completing the pre- or post-quizzes, sixth form students were asked to specify whether they studied biology, chemistry, or both subjects. Depending on their response, the quiz directed participants to the appropriate quiz questions – students who studied either subject would answer the appropriate MCQs (10 chemistry or 11 biology questions), and students who studied both chemistry and biology were required to answer a total of 19 MCQs (two biology and chemistry questions overlapped). The questions were created by adapting approved past examination questions available on the following biology and chemistry A-level examination board websites; AQA, Edexcel, CIE and OCR. The quizzes used for undergraduate students comprised 19 MCQs. There was no access to approved past examination questions from stage 2 Pharmacy courses, so the questions were taken from the same pool of questions used for the sixth form students. The content was included in the intervention tool and was still applicable to their education at stage 2 of their MPharm course – the content of the AR tool was reviewed by both sixth form and undergraduate tutors (Chapter 5.9.2). The following list details the topics of questions used in the sixth form and undergraduate quizzes; polysaccharide formation and binds, stages of mitosis,

formation of triglycerides and phospholipids, enzyme activity, DNA nucleotides, Phospholipid liposome formation, properties of water molecules, the structure of fatty acids, structural isomerism, dative bonding, shapes of chemical structures carbon 13 NMR, types of chemical compounds, zwitter ions and pka, chiral centres, formation of an ester.

5.7.3 Video Call One-on-One Semi-Structured Interviews

As mentioned in section 4.5.3, focus groups were initially intended to be the final stage of the data collection process. However, due to COVID-19 social distancing restrictions and the pandemic's effect on participant numbers, video call one-on-one semi-structured interviews were conducted in place of focus groups. Each interview took place using Zoom's web-based video conference platform. The interviews were recorded using Zoom's audio record function, which automatically and securely sends the audio file to the host's email address.

As stated in section 5.2, the interview questions were based on the perspectives shared by both sixth form and undergraduate students with regard to their thoughts on their education before and after the introduction of the Pharma Compounds AR tool (Appendix 1). Analysis of the qualitative questionnaire data (5.8.1) revealed themes and subthemes that contributed to a series of questions to explore further the ideas and concepts shared. As such, the interview was split into two main parts. The initial series of questions focused on preferred styles and methods of learning that participants had experienced and favoured, as well as the confidence associated with their performance and knowledge in those sessions. Additionally, participants were asked to explain what aspects of education gave learners the most significant motivational drive to learn.

The second section of the interview focused on participants' opinions of the AR tool, the way it was, or could be used in chemistry, biology, and pharmacy HE, specific topics or features of the tool that learners found helpful in their education, perceived changes learners experienced when using the cards concerning their knowledge, attitudes, and motivation towards learning. Further to these topics, participants were also asked to discuss ways the Pharma Compound AR tool could improve its function and content.

The questions developed and used in the video call interviews were based on the Normalisation Process Theory (NPT) framework (May, 2006; Murray *et al.*, 2010). The NPT is a theoretical framework that allows for multidimensional analysis of interactions that dictate the degree to which a complex intervention is embedded in a social system - both at an individual level and collectively in a broader context, in this case, normalising the use of the Pharma Compounds AR tool in education environments (Scantlebury *et al.*, 2017). The framework consists of four overlapping interrelated domains that relate to the context of the intervention; coherence, cognitive participation, collective action, and reflexive monitoring (Murray *et al.*, 2010). Coherence relates to participants being able to make sense of the new technology, understanding how it differs from what they have experienced before and the potential value it may bring (Bracher and May, 2019). Questions such as ‘what specifically about your preferred styles of learning did you enjoy the most?’, ‘what were your initial thoughts on the Pharma Compounds tool before its use?’ and ‘Did the AR tool help you better understand or re-enforce certain topic areas?’ were associated with the coherence domain. The second domain, cognitive participation, refers to the practices stakeholders must perform to support the new intervention, i.e., what activities could tutors and learners perform that would support or encourage the use of the

educational tool (Bracher and May, 2019; Murray *et al.*, 2010). This domain resulted in interview questions that explored participants' initial thoughts of how they would plan to use the tool during the intervention period – 'How did you imagine the AR tool would fit into your current learning routine?' and 'What would be the ideal way to use the AR learning tool according to you?'. Collective action is the third domain of the NPT and encompasses the operational work of implementing the intervention and how the use of the AR tool affected educational sessions. Questions such as 'Could you explain how you used the AR educational tool during your studies?' and 'did your use of the AR educational tool change as time went on?'. The final domain, reflexive monitoring, evaluates the implementation process to promote the embedding of the intervention (Bracher and May, 2019; Murray *et al.*, 2010). This domain led to interview questions that explored participants' trust in the AR intervention tool and questions such as 'Would you use a similar learning tool in other aspects of your learning?' and 'Do you think your attitude and motivation in other subject areas would change if you were introduced to similar types of learning tool for those areas?'. As mentioned, the four domains are not linear but share a dynamic relationship where one domain may shed light on the intervention's underperformance in another that must be addressed to reach successful normalisation.

The responses to these questions helped develop an understanding of what both students and tutors would require from the AR intervention tool for it to be successfully implemented in HE. The interview was initially guided by the lead researcher, who explained the format of the interaction and what topics would be covered. The responses of the participants then directed the interview; interviewees were allowed to express their thoughts and opinions in their own words. Although an interview protocol (Appendix 44)

was created, the semi-structured nature of the interview allowed the interview to flow naturally. In addition, the interview guide (Appendix 44) was used to ensure participants had the opportunity to respond to all proposed questions.

All participants were given an additional participant information sheet and were required to complete an online consent form (Google Forms) that allowed for digital audio recordings and anonymised quotes in future publications (Appendices 33, 34, and 35). The audio recordings were then transcribed verbatim for analysis (section 5.8.3). Reflective notes were taken during and after each interview to ensure aspects of the interview would not be missed in the transcription process. These notes included comments the lead researcher regarded as notable – (time stamps of meaningful responses, physical reactions to questions and responses).

5.8 Data Analysis

5.8.1 Pre- and Post-Questionnaires

All pre- and post-questionnaire data collected were screened for completeness. Any partially completed questionnaires could not be submitted for collection as every question was marked as 'required'. Therefore, every submitted questionnaire was completed with a response for every question.

Quantitative questionnaire data was initially imported into Microsoft Excel from Google Forms before being imported into SPSS Statistics (version 27), where descriptive and inferential statistical analysis was carried out. Descriptive statistics involving calculations of the mean, median, mode and range were used to analyse results from both the pre- and

post-questionnaires of sixth form and undergraduate participants after reviewing participants' demographic data. The median scores of non-IMI Likert type items in pre- and post-questionnaire were calculated for year 12 and undergraduate participants, respectively. Data collected from Likert type items and scales are often considered ordinal, where responses are rated and ranked, but the distance between each point cannot be measured and may not be equidistant apart (Sullivan and Artino Jr, 2013). Thus, participants may perceive the distance between 'strongly agree' and 'agree' as not the same as the distance between 'strongly disagree' and 'disagree'. In these instances, descriptive statistics such as means and standard deviations may not be the most appropriate way to describe Likert type data. For example, the average of 'strongly disagree, disagree, neither, agree and strongly agree' may not be appropriate when handling ordinal Likert data. Additionally, if responses are clustered at the extremes, the mean may appear to be the middle neutral point (Jamieson, 2004; Sullivan and Artino Jr, 2013). Due to such observations, researchers and experts argue that the median is the best way to identify the central tendency of individual Likert type items (Boone and Boone, 2012).

However, when Likert data is generated from a scale (as opposed to individual Likert type statements), it is considered interval data. The differences between each Likert anchor point can be calculated when data is considered interval data. Intervals between successive values of the ordinal scale are equally spaced, creating an interval scale such as 'strongly agree' associated with the number 1, 'agree' with the number 2, 'neither' with the number 3 etc. (Wu and Leung, 2017). The numerical values associated with each Likert point relate to a measurable entity and thus can be subjected to mean calculations, standard deviations and parametric tests (Carifio and Perla, 2008). Therefore, data generated from the IMI

scales were considered interval data and subject to mean calculations (Boone and Boone, 2012; McAuley *et al.*, 1989; Ryan and Deci, 2004, 2000). Responses from statements within each subscale were composited, and the mean response for year 12 and undergraduate students were calculated, respectively. Additionally, Likert data collected from non-IMI and IMI statements were tabulated as a percentage distribution of responses for each Likert item, as this has been a suitable method for illustrating the spread of Likert data (Jamieson, 2004; Sullivan and Artino Jr, 2013).

Experts have also argued for and against parametric or non-parametric statistical tests on Likert data. The belief that parametric tests cannot be applied to ordinal Likert type data stems from the notion that respondents may not perceive the intervals between two adjacent anchor points as equal to the interval between another two adjacent points (Gardner and Martin, 2007; Jamieson, 2004). However, other researchers have argued that increasing the number of points on a Likert scale can shift data towards continuous scales and normality, thus supporting the use of parametric statistical tests without fear of 'coming to the wrong conclusion' (Hodge and Gillespie, 2007; Jamieson, 2004; Leung, 2011; Norman, 2010; Wu and Leung, 2017). For example, a 2017 study by Mircioiu and Atkinson compared the use of a t-test (parametric) and chi-squared (non-parametric) analytical methods on Likert scale data. They found that applying the parametric test led to, practically in all cases, the same conclusions as those drawn from the application of the non-parametric analyses. However, they did acknowledge that this could result from using large numbers of responses and similar distributions of subgroups. This idea was presented earlier by Creswell (2008), who suggested that for Likert data to be viewed as interval data, there must first be; multiple categories within a scale, equality of variance between each

value on the scale, and normality of data. The IMI Likert scales adapted for this research possessed these features and were therefore considered interval data within this study and subject to parametric analysis (Ryan, 1982; Ryan and Deci, 2004, 2000). In order to be analysed, responses were 'scored' - questions labelled with (R) were negatively phrased and required the participants' responses to be subtracted from eight to reverse the score. The means of all the Likert items of the motivation and usefulness IMI subscales were calculated and dependent two-tailed t-tests were performed to establish the presence of statistical significance between the mean pre- and post-intervention responses.

The open-ended questions in both the pre- and post-intervention questionnaires were analysed using content analysis. This method encapsulates many analytical approaches that range from intuitive and interpretive analysis to rigorous and systematic textual analysis (Rosengren, 1981). Content analysis can go beyond examining language to classify large amounts of data into an efficient number of categories representing similar meanings (Hsieh and Shannon, 2005; Weber, 1990). These categories can be either explicitly communicated or inferred. Its goal is to objectively and systematically identify specific characteristics within qualitative data. Through the use of this analytical technique, large quantities of data were processed in a replicable fashion to highlight the frequency with which participants reported similar or differing opinions (Downe-Wamboldt, 1992; Stemler, 2000). Researchers read textual data word by word to derive codes that capture the core concepts of each statement at the same time as making notes of their initial analysis. As the review process continues, labels representing more than one key thought often emerge directly from the raw data and develop into the coding scheme (Hsieh and Shannon, 2005). These categories are meaningfully organised into clusters (Patton, 2002).

This particular method of analysis was chosen due to its flexibility in categorising explicit or inferred statements and codes (Cavanagh, 1997; Hsieh and Shannon, 2005). Content analysis allowed for a systematic means of describing and quantifying potential factors that affect the learning process, such as; changes in participants' motivation towards learning both with and without the use of AR, how the intervention tool may have changed individual and group learning processes, as well as ways in which individuals would have liked the Pharma Compound tool to function to best support their learning. Researchers can make replicable and valid inferences from data through this analysis method to provide new insight, knowledge and representation of facts (Krippendorff, 1980). Content analysis inherently brings an element of validity as the more frequently a code or theme occurs in the data set, the more valid the inferences and findings may be.

Responses to all open-ended questions were imported from Google Forms to Microsoft Excel for coding. Similar codes were arranged into individual columns and then grouped into categories, and the frequency was counted (Hsieh and Shannon, 2005). As expected, a range of comments made by participants was received, and therefore, the data sets needed to be carefully screened inductively to ensure each response was coded appropriately.

5.8.2 Pre and Post Knowledge Based Quizzes

All MCQs on pre- and post-intervention knowledge-based quizzes were marked as either correct or incorrect, and one point was awarded to each correctly answered question. In addition, statistical analysis was carried out to determine any changes in participants' knowledge that may be associated with using the AR Pharma Compound tool. Each

submitted quiz was complete as each question was set to require an answer before submission (Brick and Kalton, 1996; Pampaka *et al.*, 2016). Participants who may have completed one of the pre- or post-quiz and not the other were included in the descriptive analysis. However, only participants who had completed both were included in the inferential analysis as this method paired each participant's pre- and post-score.

Descriptive statistical analysis was carried out on participants' scores from both pre- and post-quizzes, which included; the range of correctly answered questions, the mean, median, and mode quiz scores, as well as the standard deviations of those scores and the percentage changes between the pre- and post-quiz scores. Descriptive statistics are often employed to summarise information gathered about a population from which the sample was taken (Larson, 2006). Here it provided a clear general summary of participants' performance on the quizzes before and after using the Pharma Compounds AR tool.

In addition, inferential statistics were used to determine whether there were any significant differences between variables of the sample population – age, gender, subject of study etc. These demographic characteristics were also gathered in the literature included in narrative synthesis (chapter 2.4.5 table 2.3). It allowed the lead researcher to determine whether or not the experimental hypothesis could be accepted or rejected (Section 3.2) (Field, 2009). A paired t-test (dependent t-test) compared the means of two related groups to determine the presence of any statistically significant differences and was used to compare the pre- and post-MCQ scores (Field, 2009; Kim, 2015). The effect of the intervention tool on students' MCQ scores was initially not known to positively or negatively affect students' performance, so two-tailed tests were used (factored into the sample size calculations in

section 5.4) (Field, 2009). To examine the differences between the mean results of students from different countries, age groups, gender, and school type, an independent t-test or an analysis of variance (ANOVA) statistical test was carried out. Independent t-tests directly compare the means of two groups, whereas the ANOVA test compares the means of more than two groups (Field, 2009). Therefore, should more than two variable groups be occupied by responses/scores from participants, the ANOVA test would have been used. Conversely, if participants' responses occupied only two variable groups, the independent t-test would have been used.

5.8.3 One-on-one Video Call Semi-Structured Interviews

The recording of each video call interview was transcribed verbatim by an experienced independent transcriber. The transcriptions were also checked against the audio recordings by the lead researcher to ensure their accuracy and to correct any discrepancies (Section 4.6.1).

Thematic framework analysis was chosen as the method of analysis to examine the video call interview data. It is a method for identifying and analysing patterns of meaning within a data set while displaying the themes that describe the concept or phenomena within columns of the framework that relate to specific priori issues in the topic under investigation (Braun and Clarke, 2006; Daly *et al.*, 1997; Gale *et al.*, 2013; Ritchie *et al.*, 2013). The final result of this process culminates in reporting all unique points made by participants and highlighting the most prominent grouping of themes and subthemes present in the qualitative data set (Joffe, 2012). Themes, with respect to thematic analysis, relate to specific patterns of ideas or meanings found within the data, either directly stated

or inferred in participant responses. Another distinction in identifying a theme is whether it has been drawn from a theoretical or other *a priori* idea or raw data. Although themes derived from theory afford researchers to replicate, extend, confirm or refute existing pieces of work, to derive themes directly from the raw data are, in many cases, the primary objective for qualitative studies (Boyatzis, 1998; Joffe, 2012).

The 7-step approach to Framework Analysis described by Gale *et al.* (2013) and the NPT framework (Murray *et al.*, 2010) were both used as a guide to carry out the thematic analysis of the video call semi-structured interviews. First, the lead researcher read and re-read each interview transcript and listened to the digital audio recordings on multiple occasions, so they were highly familiar with the data, all while making notes of the initial concepts emerging from the data. Next, initial codes were generated that captured elements of data. Each interview transcript was meticulously reviewed, and the initial codes of data were copied into Microsoft Excel spreadsheets. A horizontal row represented each interview. Codes from each interview that captured the same idea or concept were tabulated under one another and formed very early themes in conjunction with each of the four domains of the NPT framework. Within each domain, codes were further organised into more specific categories to which they relate. Once each interview had been reviewed for codes at least twice, the early themes were reviewed to ensure each code suited the theme with which it was associated. The analysis then continued to refine the specific concept of each theme and then name and organise each theme so that there was a clear story of the analysis with little to no overlap between themes. The final stage of the analysis involved the presentation of quotes that clearly illustrated the themes and subsequent subthemes to which they belong concerning the research question and literature. The

quotes and the reported discussion are presented in results Chapter 10. Analysis of the video call interviews was an inclusive process, and the very nature of framework analysis meant that any views that differed from the majority were coded and included in the analytical process (Gale *et al.*, 2013). Field notes were also kept during the interview process that aided discussions between the lead researcher and the project supervisors about emerging themes (Chapter 4.6.1).

5.9 Data Protection and Confidentiality

Participants' confidentiality was maintained throughout the entire research project in accordance with the UK General Data Protection Regulations (GPDR) Act 2018. All data and information collected were stored on a password-protected and encrypted device that only the lead researcher had access to – data consisted of electronic consent forms, questionnaires and quiz responses, digital audio recordings of interviews and their associated transcriptions. Participants were asked to provide the same email address through each stage of the study – pre-questionnaire and pre-quiz, post-questionnaire and post-quiz, and interview stages. The email addresses were used as an indicator to track participants' progression through each phase and to send participants the relevant elements of the study. Once data collection had been completed, the participants' details were removed and replaced with a unique identifier. This unique identifier was used throughout the analysis stages and in writing this thesis, publications, and reports. Great care was taken to ensure participants were not directly identifiable from data in any reports, publications or this thesis. All participants were informed via the participant information sheets and consent forms that their responses and quotes would be used in

publications and reports (Appendices 24 to 35). They were also informed that their quotes would be anonymous; therefore, they would not be directly identifiable.

5.10 Chapter Summary

This methods chapter has highlighted the methods that were used in this study. The main aim of this study was to evaluate the effectiveness of the AR system Pharma Compounds as a educational tool and to determine its effect on students' level of knowledge and motivation towards learning. Both quantitative and qualitative data collection tools and analysis were used to achieve the objectives. Participants were recruited through new and existing connections between their Sixth Forms/colleges and Keele University School of Pharmacy and Bioengineering.

Each data collection tool has been discussed concerning the type of data collected; quantitative data was acquired using pre- and post-intervention MCQs and Likert scale/type questions. In addition, qualitative data were obtained from open-ended questionnaire questions and focus group sessions. The use of mixed methods in this research has afforded the evaluation of the effectiveness of the AR Pharma Compound AR as an educational tool. The result from the pre- and post-knowledge-based quizzes are presented in chapter 7, followed by the quantitative results from the pre- and post-questionnaire in chapter 8. Chapter 9 displays the qualitative results from the pre- and post-questionnaire. Finally, chapter 10 presents the results from the semi-structured interviews.

6 Pharma Compounds AR Tool Design

6.1 Introduction

This chapter describes the design study that was carried out to develop the Pharma Compound AR educational tool used in the main body of this programme of research. Section 6.2 details the aims of this design chapter. Section 6.3 describes the design of this initial study to develop the intervention tool, followed by the ethical approval in section 6.4. The sampling and recruitment procedures are discussed in section 6.5, followed by data collection and data analysis methods in sections 6.6 and 6.7, respectively. The key findings of this study are reported in section 6.8, followed by the development process of the Pharma Compound AR tool in section 6.9. The chapter summary is found in section 6.10.

6.2 Aims and Objectives

As stated in the aims and objectives chapter, this design study aimed to obtain data from students and tutors regarding challenging aspects of their respective biology, chemistry, and pharmacy HE courses to aid the development of the AR Pharma Compound educational tool.

1. To record specific aspects of year 12 biology and chemistry content that students and tutors consider difficult to understand and visualise.
2. To record specific aspects of Stage 2 Keele University MPharm content that students and tutors consider difficult to understand and visualise.
3. To produce a series of AR Pharma Compound cards whose design and content was informed by participant data (objective 1 and 2) for year 12 biology and chemistry sixth form students and stage 2 MPharm students that will act as a learning/revision aid.

6.3 Study Design

The design of this study was explorative in nature and utilised online questionnaires to gather both quantitative and qualitative data. As discussed in chapter 1 and chapter 2, a few AR systems have been developed for use in the academic educational sector, specifically biology, chemistry, and pharmacy HE. The systems that had previously been created for educational use did not explicitly involve student stakeholders in their development (Behmke *et al.*, 2018; Gan *et al.*, 2018; Keller, 1987a; Núñez *et al.*, 2008; Salem *et al.*, 2020; Wozniak *et al.*, 2020). Khosravi *et al.*, (2020) suggested that including student stakeholders in developing educational tools as non-experts can result in a high-quality resource that meets rigorous judgmental criteria. Student involvement in the development of educational tools has even been associated with an advantage over tutor involvement – students use their knowledge of their misconceptions to formulate a resource capable of avoiding the same blind spots they experienced (Khosravi *et al.*, 2020; Nathan and Petrosino, 2003; QAA, 2018).

This design study involved input and suggestions from the sixth form and undergraduate students and their tutors. UK-based Students and tutors were given a brief presentation on AR and its many uses in various industries, followed by a hands-on practical session with the pre-existing PharmaCards Keele AR system. The session allowed participants to understand the nature and performance of an AR educational tool and what was hoped to be achieved by developing the new tool. Following this face-to-face demonstration, participants were sent an email that contained information from the presentation, a participant information sheet and consent form, a questionnaire and a video demonstration of the existing

PharmaCards Keele AR system (Appendices 3 to 18). As with the main study, participants were based in the UK and Kenya (chapter 5.2) and were recruited due to their existing relationship with Keele University School of Pharmacy and Bioengineering and their institutions' involvement in the main study. Participants based in Kenya were sent the same email received by UK-based participants. The questionnaire could only be accessed once participants had consented to participate.

Both student and tutor participants were invited to complete the short online questionnaire that consisted of Likert scale type, multiple choice, and open-ended questions, similar to those seen in the questionnaires of the main study (Appendices 15, 16, 17 and 18). The questionnaires were created and hosted on Google Drive's "Forms" platform, as mentioned in chapter 5.6. Students and tutors gained access to the questionnaire via a weblink included in an email distributed by a gatekeeper on behalf of the lead researcher. As mentioned in chapters 4.5.1 and 5.7.1, questionnaires are the most widely known and most used data collection tool in social research to gather participants' thoughts and perspectives on a phenomena (Bee and Murdoch-Eaton, 2016; Gallagher *et al.*, 2013; Tavakol and Sandars, 2014; Vilanova, 2006). Surveying both students and tutors afforded the opportunity to cross-reference suggested subject areas and, thus, provided a more holistic and complete understanding of what aspects of the courses students genuinely struggled to understand.

6.4 Ethical approval

An application for this study was submitted to the Keele University Faculty Research Ethics Committee (FMHS REC) in July 2018; approval was granted in December 2018

(ERP3150/MH-200133) (Appendix 1). The study invitation email (Appendices 3, 4 and 5), participant information sheets (Appendices 6, 7, 8, 9 and 10), consent forms (Appendices 11, 12, 13 and 14) and questionnaires (Appendices 15, 16, 17 and 18) accompanied the ethical application when sent to the review board.

6.5 Sampling and Recruitment

Purposive sampling was used to recruit participants as this study did not aim to generate widely generalisable data. The objective was to identify general content that lends itself to AR as well as challenging aspects of year 12 biology and chemistry and stage two Pharmacy courses provided by the institutions involved with the main study – one private sixth form school in the UK, two private sixth form schools in Kenya and a university School of Pharmacy in the UK (Chapter 5.2). Therefore, purposive sampling was the most appropriate sampling method to place focus on these participating institutions. Additionally, this sampling method has been known to generate relatively rich data from a limited number of participants with particular knowledge of the area under investigation (Creswell and Plano Clark, 2011; Patton, 2014). Year 13 Biology and Chemistry students, as well as year 12 Biology and Chemistry tutors from participating schools, were invited to complete the questionnaires that would gather data pertaining to Year 12 biology and chemistry course material Similarly, Stage 3 MPharm students, along with Stage 2 MPharm tutors were invited to complete the questionnaires that gathered data relating to Stage 2 of the MPharm at Keele University. Year 13 biology and chemistry students and Stage 3 MPharm students were intentionally the focus of this study as they would have recently completed the preceding year of education. Year 12 and stage 2 students were only a few months into

the academic year and would, therefore, not have completed all areas of the course at the time of this study.

Individual participants were recruited in December 2018 through similar means as participants in the main study (Chapter 5.5). Tutors (gatekeepers) were initially approached through email, inviting them to participate in the study. The email explained that the study aimed to develop and evaluate a novel AR educational tool for chemistry, biology, and pharmacy HE with student and tutor involvement. Once tutors had agreed to participate, they were asked to forward the recruitment email to their students. The recruitment emails contained a web link to the appropriate participant information sheets, consent form and questionnaire. All components (participant information sheets, consent form and questionnaire) were linked together via a single Google Drive Form – to access the questionnaire, participants will first have to read the information sheet and then complete the consent form (a very similar process to the one used in the recruitment for the main study). UK institutions (MPharm and sixth form) who had agreed to participate were visited in person by the lead researcher, where they received a brief presentation on the scope of this study and the broader thesis. In this presentation, participants had the opportunity to have a hands-on practical session with the pre-existing PharmaCards Keele AR system. After the session, students and tutors accessed the email containing the participant information sheet, consent form and questionnaire. Concerning the non-UK institutions, the lead researcher sent a recruitment email detailing the study's scope and the intention to develop an AR educational tool with a demonstration video attached. The video demonstrated the function of the existing PharmaCards Keele AR system, as they could not carry out an in-person visit. Reminder emails were periodically sent out to gatekeepers to forward to

respective students, encouraging students who had failed to complete and submit the questionnaire to do so as soon as possible.

6.6 Data collection

As mentioned in section 5.3, a questionnaire was the data collection tool for this short design study. Questionnaires were one of the data collection tools used in the main study; although the same style of questions was used in this design study (multiple choice, Likert scale type and open-ended questions), the specific questions were not the same. The methodology behind questionnaire design has previously been discussed in the Methodology and Methods chapters 4.5.1. and 5.7.1. Four of the seven questions were open-ended so participants could be unrestricted when providing topics and potential reasons why these topics were perceived to be difficult to learn (Roopa and Rani, 2012). A single five-point Likert type question was included for participants to rank the perceived difficulty of their most difficult topic provided (Rickards *et al.*, 2012). The final two questions were closed-ended (yes or no) questions (Roopa and Rani, 2012). The questionnaire for this design study began with an open-ended question that asked participants to list the top five areas of their course that they perceived to be difficult to learn and understand, starting with the most difficult. The following question was a Likert type statement that required students to rank the difficulty of the most difficult topic (1=very easy, 5=very difficult). Likert type questions are beneficial when measuring less concrete concepts such as the perceived difficulty of subject material as with this scenario (Rickards *et al.*, 2012). The open-ended questions that followed allowed participants to explain their responses further and provide context to their perspectives (Creswell, 2014; Yauch and Steudel, 2003).

6.7 Data Analysis

Qualitative data from the questionnaires were analysed using the content analysis (Hsieh and Shannon, 2005; Rosengren, 1981; Weber, 1990). Comments and responses provided by participants were coded into common themes. The frequency at which themes appeared was then counted and tabulated. Open-ended questions where participants were asked to rank their most difficult topics were also analysed with content analysis. Content analysis was discussed in greater detail in section 5.8.1. The analysis of particular qualitative questions underwent descriptive statistical analysis in addition to content analysis (questions 4 of the student questionnaires and questions 1 of the tutor questionnaires). The top 5 most difficult subjects were analysed by content analysis, where recurring themed topics were grouped. Each theme underwent descriptive statistical analysis to highlight the median occupied position when included in participants' top 5 lists. Concerning the quantitative data analysis, descriptive statistical analysis was carried out on the Likert type, ranked and multiple-choice questions.

6.8 Key findings

6.8.1 Demographic Results

Tables 6.1 to 6.3 display the demographic data collected from tutors and students involved in this design study. In total, 97 students and 13 tutors were involved in the design of the Pharma Compound cards – 38 students and six tutors provided data related to year 12 biology and chemistry course material, and 59 students and seven tutors provided data associated with stage 2 of the MPharm course. No demographic data were related to the MPharm tutors as the 'subject' and 'examination board' categories did not apply.

Sixth Form Student Demographic Data	Category	Number of participants
Gender	Female	24
	Male	13
	Prefer not to say	1
Age	16 - 17	22
	18 - 19	13
	19+	3
Country	Kenya	10
	United Kingdom	28
	Hong Kong	0
Subject	Biology	4
	Chemistry	4
	Biology and Chemistry	30
Examination Board	AQA	3
	Edexcel	8
	Cambridge International Education	10
	BTEC	5
	Pearson (Edexcel)	8
	OCR	3

Table 6.1 displays the demographic data for year 13 sixth form student participants

Sixth Form Tutor Demographic Data	Category	Number of participants
Country	Kenya	0
	United Kingdom	6
	Hong Kong	0
Subject	Biology	3
	Chemistry	2
	Biology and Chemistry	1
Examination Board	AQA	3
	Edexcel	0
	Cambridge International Education	0
	BTEC	0
	Pearson (Edexcel)	0
	OCR	3

Table 6.2 displays the demographic data for year 12 sixth form tutor participants

Undergraduate Student Demographic Data	Category	Number of participants
Gender	Female	38
	Male	21
	Prefer not to say	0
Age	19 – 21	48
	22 – 25	9
	25+	2
Type of student	Domestic	10
	International	28

Table 6.3 displays the demographic data for stage 3 MPharm student participants

6.8.2 Questionnaire Data

Content analysis of the open-ended questions within the questionnaires brought forth a series of key themes:

- Particular subject areas within year 12 Biology and chemistry courses, as well as the Stage 2 MPharm course that are subjectively difficult to grasp.
- Perceived levels of difficulty for the suggested subjects.
- Perceived reasons as to why suggested subject areas are difficult to learn and understand.

Tabulated in table 6.4 are the subject areas suggested by students and tutors. The table has been separated to display themes/subject areas suggested by Year 13 students and Year 12 tutors before displaying the data collected from MPharm Stage 3 students and Stage 2 tutors. Each theme or subject area is accompanied by the frequency at which they appeared in both students' and tutors' responses – specific topic elements included in participant responses have also been included in the table.

Theme/Subject Area	Number of Students/Tutors		Specific Topics/Structures
	Students	Tutors	
Sixth form Participants			
Organic Chemistry	22	4	*Alkanes; Alkene; Isomerism; Nomenclature; Acids and bases; Carbonyl compounds*
Biochemistry	13	1	*Proteins; Amines*
Cell transportation	6	1	*Transportation in animal cells; Transportation in plant cells*
Anatomy and Physiology	16	0	*Muscles; Central Nervous System; Cardiovascular system; Kidneys; Digestive system; Respiratory system; Blood*
Analysis	7	1	*Spectroscopy; Electrophoresis; Nuclear Magnetic Resonance*
Inorganic Chemistry	8	2	*Group 2 elements; Ionic bonding; Group 17 elements; Transition elements; Halogen derivation; Redox reaction; Oxidation numbers*
Biological Cells/ Cell division	12	0	*Cell membrane structure; Organelles; Mitosis; Meiosis; Cellular respiration*
Equations and calculations	10	3	*Arrhenius equation; Mole calculations; Back titration calculations*
Genetics/DNA	12	1	*Genetic modification/engineering; Transcription and translation, Nucleic acid; Protein synthesis*
Other Topics			*Enthalpy changes; Hess' cycle; Partial pressure; Properties of water; Medical physics; Orbitals; standard solutions; Bond angles; Electronegativity; Polarity; Classification of evolution; Evolutionary inheritance*
Undergraduate Participants			
Pharmacokinetics	35	3	*Quantitative pharmacokinetics; Metabolism; Chemical kinetics*
Pharmaceutical Science	41	2	*Interfacial phenomena; Colloidal dispersion; Emulsions; Rheology; Particle flow; Drug stability; Electrical bilayer; Lipophilic and hydrophilic compounds*
Pharmacodynamics	9	0	*Gastrointestinal therapeutics*
Drug/Medicine formulation	28	0	*Quality Assurance/Quality Control; Creams and ointments formulation; Aseptic techniques; Drug delivery to*

Theme/Subject Area	Number of Students/Tutors		Specific Topics/Structures
	Students	Tutors	
			the lungs; Drug delivery through the skin
Chemistry	25	2	*Chiral centres; Common chemical structures; Aromaticity and aromatic chemistry; Medicinal chemistry; Organic chemistry; Nucleophilic addition;*
Calculation	3	5	*Assay calculations; Serial dilutions/calibration curves; Pharmacy practise calculations; Pharmacokinetic calculations; Equilibrium constants*
Chemical Analysis	18	2	*Nuclear magnetic resonance; Mass spectrometry; Chromatography*
Anatomy	3	0	*Blood brain barrier; Gastrointestinal system; Lungs; Kidney*
Law Ethics and Practise	3	3	*Consultation skills; Controlled drugs, Accuracy checking*
Other Topics			*Microbiology; Decision Making, Synoptic assessment*

Table 6.4 displays the themes/subject areas, the number of times they were mentioned, and an example taken from the open-ended questions

When sixth form students and tutors ranked their top five most difficult subject areas, no subject area held a median position of one (first in the list of the most difficult subject areas). Instead, organic chemistry, biochemistry, genetics, and cell division subject areas all had a median position of two as the second most difficult subject area. The remaining six subject areas: cell transportation, anatomy and physiology, analysis, inorganic chemistry, equations and calculations, and other topics, each had a median position of three as the third most difficult subject area. When included in the sixth form participants' list, organic chemistry subjects were found most frequently first at the top of the top five most challenging subject areas.

Concerning the subjects suggested by undergraduate students and their tutors, no subject areas occupied a median ranked position of one as the topmost difficult subject. A median ranked position of two was secured by pharmacokinetics, pharmaceutical science, and chemistry topics (median position of second most difficult subject area). Aspects of the course that involved calculations had a median rank of 2.5, with pharmacodynamics and chemical analysis subject areas having a median rank of three when listed in the top five most difficult subjects. The remaining subject areas, drug formulation, law ethics and practice, and anatomy, have a median position of four, 4.5 and five, respectively, when listed among the five most difficult topics.

Participants were then asked to rate the difficulty of the subject area they had listed as the most difficult. A Likert type statement with five anchor points that ranged from 1 (very easy) to 5 (very difficult) was used. Concerning the sixth form student and tutor participants, organic chemistry topics were most frequently ranked as the most difficult subject area (n=14) with a median difficulty of 4 (difficult). The second most commonly ranked most difficult subject areas were genetics (n=5) and equations and calculations (n=5) with a median difficulty of 4 (difficult) and 5 (very difficult), respectively. Biochemistry (n=2), Physiology (n=2) and biological cell/cell division (n=2) subject areas are all third most frequently ranked most difficult subject areas with median scores of 4.5, 4.5 and 4, respectively.

When looking at the undergraduate students' and tutors' responses, pharmaceutical science (n=24) topics were the most frequently ranked as the most difficult subject areas, with a median difficulty of 5 (very difficult). The second most frequent subject area ranked

by difficulty was pharmacokinetics (n=12) with a median difficulty of 4 (difficult). The next most frequently ranked subject area by undergraduate students and tutors was chemistry-related topics (n=8) with a median difficulty score of 5 (very difficult).

The following questions asked student participants to select one of three options as the main potential source of difficulty they experience when studying learning material. The results are tabulated below in table 6.5.

Reason for difficulty	Sixth Form	Undergraduate
Complexity of the topic	14	34
Low interest in the topic	3	15
Visualising learning material	21	10

Table 6.5 displays the number of times each reason was selected by students

Both undergraduate and sixth form students were also allowed to provide additional reasons as to why students found particular subject areas difficult; several participants reiterated that their difficulty originated from one of the three options tabulated above. However, there were indeed other additional reasons suggested. Table 6.6 details the frequency at which potential reasons were reported.

Reason for difficulty	Sixth Form	Undergraduate	Quote Example
Complexity of the topic	5	17	*"Complexity of the [chemical] structures."* [Stage 3 MPharm student]
Low interest in the topic	1	12	*"Lacking motivation as did not enjoy subject."* [Stage 3 MPharm student]
Visualising learning material	10	12	*"Difficult to visualise flow of liquids and the forces involved"* [Stage 3 MPharm student]
Quantity of learning material	7	2	*"There is a lot of information to retain in order to understand them."* [Year 13 student]
Format of the teaching session	1	6	*"Some aspects were difficult to comprehend in the format that they were presented in"* [Stage 3 MPharm student]
Lack of interactivity	1	1	*"Because the lecturers didn't make it interactive enough and didn't check understanding"* [Stage 3 MPharm student]
Incomplete or insufficient explanation of subject	9	4	*"It requires a lot of research and sometimes the internet doesn't have the answers"* [Year 13 student]
Short amount of time to learn material	7	2	*"There is too much content to learn in a short amount of time."* [Year 13 student]

Table 6.6 displays the additional themes of difficulty, the number of times they occurred, and an example taken from the open-ended questions provided by students.

Tutors were also asked to provide potential reasons why they may believe students found specific topics difficult. The suggested possible reasons why students find particular issues difficult to understand were extracted from data using content analysis and tabulated in table 6.7 with quoted examples of comments made.

Reason for difficulty	Sixth Form	Undergraduate	Quote Example
Complexity of the topic	3	3	*"The level of complexity involved; decision-making draws on many different skills/abilities e.g., personal confidence/self-image, emotional intelligence, reasoning, factual/subject knowledge."* [Stage 2 MPharm tutor]
Low interest in the topic	2	1	*"Plant biology and diversity isn't as interesting as human biology"* [Year 12 Sixth form tutor]
Visualising learning material	1	1	*"Visualisation of molecules."* [Year 12 Sixth form tutor]
Application of Knowledge	2	2	*"Not simply regurgitation but need to understand concepts and apply them."* [Stage 2 MPharm tutor]

Table 6.7 displays the themes of difficulty, the number of times they occurred, and an example taken from the open-ended questions provided by tutors.

Towards the end of the questionnaires, all participants were asked to suggest specific chemical structures they had come across during the year 12 and stage 2 MPharm courses, which they or students they teach struggled to visualise. The suggestions have been added to table 6.4 under the heading "specific topics/structures". Finally, all participants were asked whether they believed using a 3D interactive educational tool that could display chemical structures, objects, and course material would help students better understand topics. Table 6.8 below details the breakdown of both student and tutor responses.

Response	Sixth Form		Undergraduate	
	Students	Tutors	Students	Tutors
Yes	37	6	55	5
No	1	0	4	2

Table 6.8 displays the number of students and tutors who believe not a 3D visual learning aid would encourage the learning process.

Questionnaire results indicated that most sixth form students found topic areas that required a certain level of understanding of chemical structures and their properties/characteristics most difficult. These included organic chemistry, biochemistry and genetics/DNA topics which were also reported in the responses of their tutors.

Additionally, sixth form students found topics involving anatomy and physiology similarly difficult, all of which involved detailed anatomical processes and cascades at a molecular level. Concerning undergraduate participants, students subjectively reported pharmacokinetics and pharmaceutical science topics as the most difficult to learn and understand. A commonality in the shared topics reported by both groups centred around concepts and processes that were physically unobservable such as signalling cascades within cells or interactions between different chemical functional groups, which required learners to use visual representations to aid the learning process. Both groups of students reported that the complexity of the topics and the poor visualisation of learning material were perceived as significant reasons why they struggled to comprehend these subject areas, further pointing to a need for more appropriate educational aids to support their current methods. This observation ties into the literature's findings in improving students' visualisation and spatial abilities to enhance their learning experience (Dunleavy *et al.*, 2009; Klopfer and Squire, 2008; Wu *et al.*, 2013). Subsequently, nearly all participants in this design study indicated that they would welcome a 3D interactive educational tool to support their education.

6.9 Pharma Compound App Development

The purpose of this design study was to gather data from past students and current tutors to highlight particular topics that are difficult to learn. This information was used to guide the educational content incorporated into the novel educational tool – Pharma Compounds AR App.

The lead researcher headed the research team in reviewing the stage 2 MPharm and Year 12 Biology and Chemistry syllabi provided by examination boards listed in tables 6.1 and 6.2. An extensive list of potential topic areas, taken from syllabi and the collected data seen in table 6.4, along with potential ways of displaying the academic content, were discussed amongst the supervisory team and Digital Development Team (DDT).

6.9.1 Existing PharmaCards Keele App

The intervention tool used in the main study was based on the software and programming of an existing augmented reality tool developed by the Keele University School of Pharmacy – PharmaCards Keele App. This AR app can be classed as an image or target-based AR system. As mentioned in the Introduction Chapter 1.9, image-based AR systems require a specific 'target' or unique image that the device's camera can capture. Once the system has recognised the unique image, the programmed computer-generated information associated with the unique image is displayed on the users' view of the real world - The view being the screen of the mobile or tablet device.

As with most image-based AR systems, the original AR tool employed two main components, excluding the mobile device: The mobile application (software) and the physical playing cards (2D target images). All the playing cards of the PharmaCard Keele system followed a uniform layout but incorporated unique patterns that significantly differentiated one card from the other – each card has a simple heading with a 2D image below that represents the associated computer-generated information that will be displayed once it has been scanned. The image on the face of each card plays a vital role in the system's ability to identify and differentiate each card from another.

The educational content of the original PharmaCards Keele app centred around the molecular structures of several pharmaceutical drugs (e.g., amoxicillin, aspirin, paracetamol, ibuprofen, and metformin). The system was limited to only recognising and displaying the 3D content of one card at any particular time. The computer-generated imagery was accompanied by a sliding window that showed the text to support the on-screen 3D structures. The system also allowed the user to rotate the onscreen models along two axes by dragging a finger from one side of the screen to the other.

6.9.2 Pharma Compound Educational Content and Functionality

After understanding the basic principles of the existing augmented reality app, the next step was to generate the educational content that would be implemented into the new educational tool. The research team, led by the lead researcher, reviewed all the Biology and Chemistry course syllabi of participating sixth form schools and the Keele MPharm course syllabus. Topic areas and material perceived to translate well into three-dimensional representations for each respective course were noted and put forward as potential options for the educational tool.

As previously mentioned, academic content for this app also came from the suggestions made by students and their tutors. After analysing the data, all subject and topic areas mentioned were ranked to identify the most frequently suggested themes (Table 5.4). The two lists of topics from both sixth form and undergraduate participants were then cross-referenced to highlight topics that students mutually reported finding particularly difficult to understand but also material that would translate well into an augmented reality

environment. It became apparent that although the syllabi of the sixth form chemistry and biology courses are inherently different to the Keele University MPharm course, many of the latter's core principles and ideology are founded in those of the former. There were many similarities in the topics and themes suggested by both sixth form and undergraduate students. The data generated from the questionnaires provided insight into the broad topics reported by participants. From this initial list ('specific topics' column in table 6.9), the lead researcher reviewed the syllabi of the sixth form and MPharm courses and discussed potential options for AR model/animation and functionality for each card with the respective course tutors and further discussed with the supervisory team. Tabulated in table 6.9 is the list of preliminary topics generated from student and tutor suggestions, exam syllabi, and the research team. The card functionality column details the form of 3D AR animation and the additional on-screen features when a card is scanned.

Theme	Specific Topic	Final Pharma Compound Card	Card Functionality
Biochemistry	Carbohydrates	Alpha Glucose	• Standard chemical structure • On screen button switch to maltose chemical structure • Combine with Galactose to form Lactose • Combine with Fructose to form Sucrose
		Beta Glucose	• Standard chemical structure
		Galactose	• Standard chemical structure • Combine with Alpha Glucose to form Sucrose
		Fructose	• Standard Chemical structure
	Proteins	Glycine	• Standard Chemical structure • Combine with Alanine to form a polypeptide
		Alanine	• Standard Chemical structure • Combine with Glycine to form a polypeptide
	Adenosine Triphosphate	Adenosine Triphosphate	• Standard chemical structure
	Triglycerides	Phospholipids	• Standard chemical structure
		Trimyristin	• Standard chemical structure
	Neuromuscular Junction*	N/A	N/A

Theme	Specific Topic	Final Pharma Compound Card	Card Functionality
Biology	Cell Division	Mitosis	• 3D static animation • On screen buttons to cycle through stages of mitosis
Chemistry	Chirality	Chiral Centres	• Standard chemical structure
	Acids and Bases	Zwitter Ion	• Standard chemical structure • On screen buttons to cycle though positive, neutral, and negative ions
	Bonding	Giant Covalent Bonding	• Standard chemical structure
		Dative Bonding	• Standard chemical structure
	Alcohol	Ethanol	• Standard chemical structure • Combine with ethanoic acid to form an Ester
	Carboxylic Acid	Ethanoic Acid	• Standard chemical structure • Combine with ethanol to form an Ester
	Isomerisation	E/Z Isomers	• Standard chemical structure • On screen button to swap between E and Z isomers
	Behaviour of water	Water	• Standard chemical structure
Genetics/DNA	DNA Nucleotides	DNA Base Pairs	• Standard chemical structure • On screen button to swap between the two different DNA base pairs
	DNA Double Helix*	N/A	N/A
	DNA Replication*	N/A	N/A
Chemical Analysis	Nuclear Magnetic Resonance	Chlorocyclohexane	• Standard chemical structure • Carbons in the same NMR environment colour coded
Enzymes/ Pharmacokinetics	Metabolism	Enzyme-Substrate Complex	• Short animated video clip
		Enzyme Inhibition	• Short animated video clip
		Enzyme Inhibition (Non-Competitive)	• Short animated video clip
		Enzyme Inhibition (Uncompetitive)	• Short animated video clip
Pharmaceutical Science	Rheology*	N/A	N/A
	Particle flow*	N/A	N/A
	Emulsions*	N/A	N/A
	Drug Delivery to Lungs*	N/A	N/A

Table 6.9 displays the subject areas considered for the educational tool and those selected for the final AR system. *Topics that could not be produced due to limited time and programming issues.

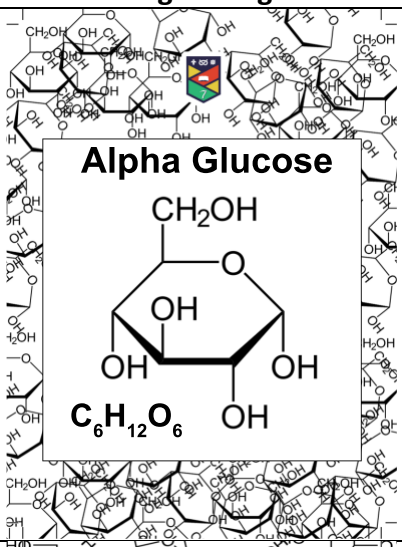
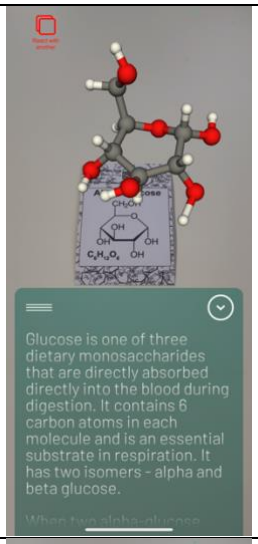
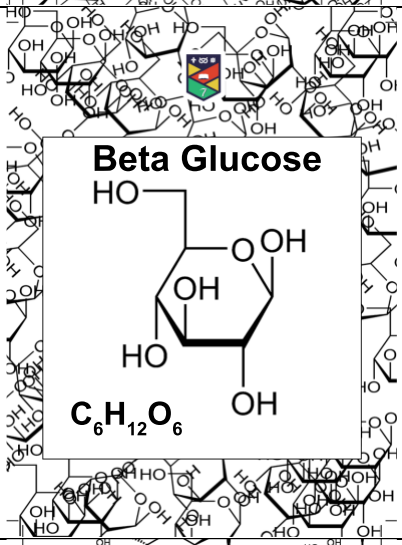
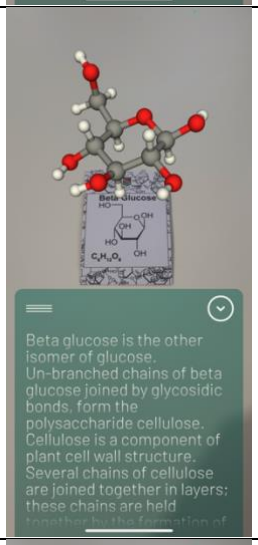
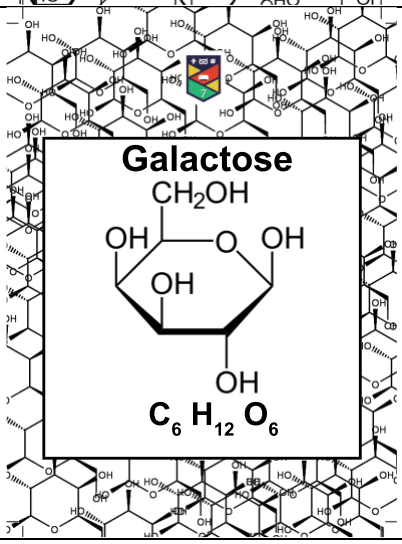
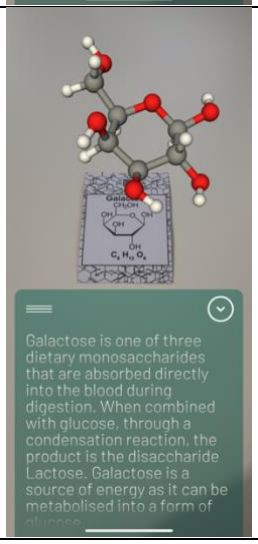
It was also imperative that the DDT were involved in discussions surrounding the cards' content, as the content affected the cards' functionality. As mentioned in section 6.9.1, the existing system allowed only one target to be scanned at any particular time. After a more

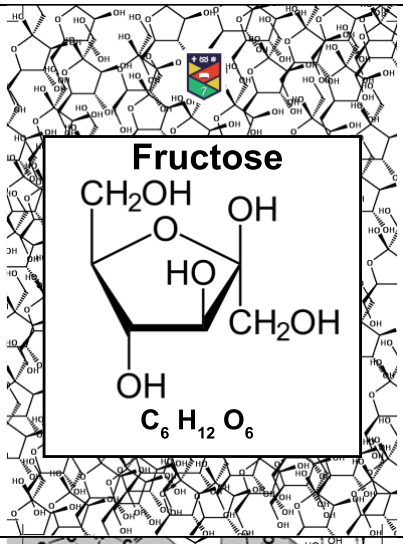
in-depth look at the Unity system used in the PharmaCards Keele AR system, it became apparent that the parameters had been limited to registering only one target image at a time. The Unity programming system, however, could allow up to five target images to be scanned, registered and 3D models displayed at any time. Additionally, the system could allow up to five cards to be placed close to each other, forming a brand-new target image and producing a new 3D representation.

The programming and functionality development intentionally began with the Ethanol and Ethanoic acid cards. These two cards allowed exploring the capabilities of the Unity system even further. In particular, the function to create an entirely new target image from two separate targets. This test version of the APP was launched to ensure the system correctly functioned on different devices (May 2019). Following the successful completion and publication of the test version, the DDT continued to programme the remaining cards that were based on the ball and stick models of chemical structures (Alpha Glucose, Beta Glucose, Galactose, Fructose, Glycine, Alanine, Adenosine Triphosphate, Phospholipid, Trimysristin, Chiral Centres, Zwitter Ion, Giant Covalent Bonding, Dative Bonding, E/Z Isomers, Water, DNA Base Pairs and Chlorocyclohexane). The remaining cards (mitosis, enzyme-substrate complex, and conventional, non-competitive, and competitive enzyme Inhibition) were programmed to include simple animations that looped when the target images were scanned (completed September 2019).

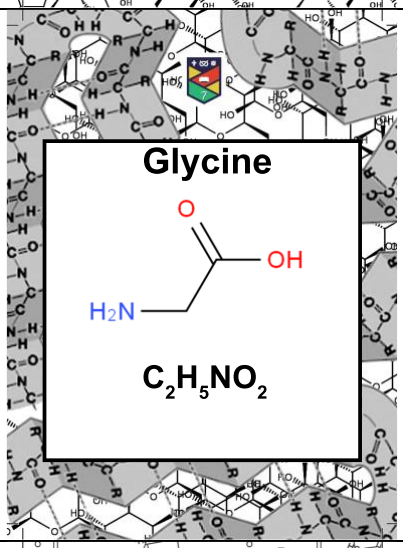
If available, the 3D models for the Pharma Compounds card ball and stick chemical structures were downloaded from Chemspider (Royal Society of Chemistry, 2022) as .mol files. If they were unavailable from this website, models were created in Maya 3D

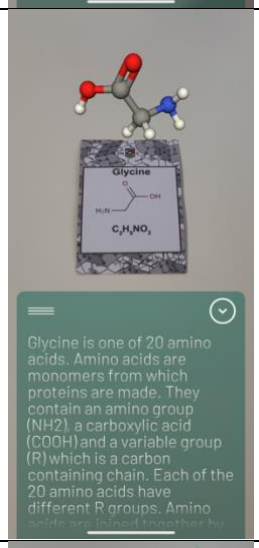
application as .mol files. Both types of 3D models were then opened in the jMol software program and exported as .fbx files into Unity, where they were linked to their respective Pharma Compound target images. The remaining 3D models and animations were also created in Maya and transferred into Unity, where they were linked to their respective target images. The programming for creating a new target image by combining two existing target images, the onscreen button functionality, and the text accompanying the 3D models and animations were also programmed within Unity. The lead researcher wrote the educational text and reviewed with sixth form and undergraduate tutors to ensure its appropriateness for students. The source of this material was obtained from free-to-access online revision guides created specifically for AQA, Edexcel, CIE A-Level chemistry and biology students. Once the models and respective target images had been programmed and completed, the application was uploaded onto the Google Play and App stores for mobile and tablet download. Table 6.10 details the complete list of all the Pharma Compound target images and the associated 3D models captured on screen.

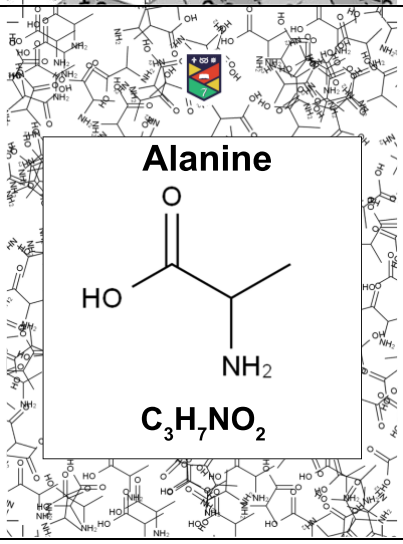
Target Image	On Screen 3D Model
	
	
	

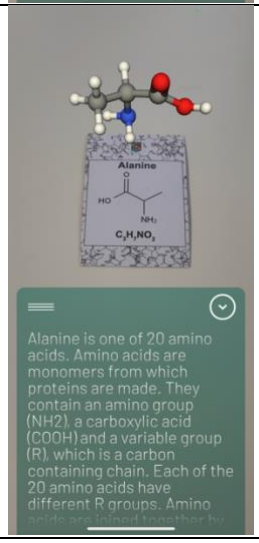

Fructose
CH_2OH
OH
O
HO
CH_2OH
OH
$C_6H_{12}O_6$

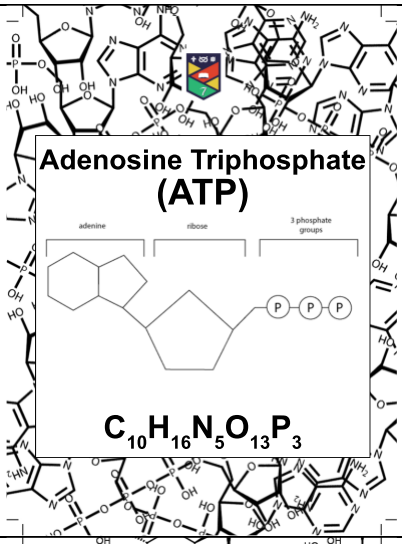

Fructose is one of three dietary monosaccharides that are absorbed directly into the blood during digestion. When combined with glucose through a condensation reaction, the product is the disaccharide Sucrose. The metabolites of fructose can be used to generate glucose for energy


Glycine
O
OH
H_2N
$C_2H_5NO_2$

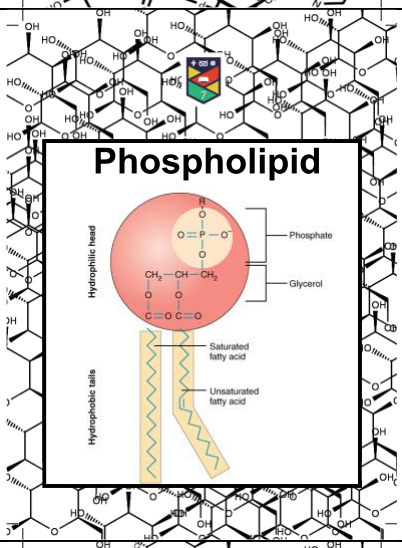

Glycine is one of 20 amino acids. Amino acids are monomers from which proteins are made. They contain an amino group (NH2), a carboxylic acid (COOH) and a variable group (R) which is a carbon containing chain. Each of the 20 amino acids have different R groups. Amino

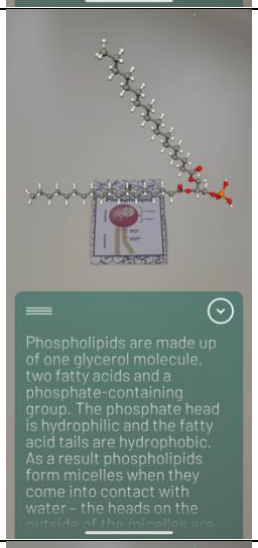

Alanine
O
HO
NH_2
$C_3H_7NO_2$

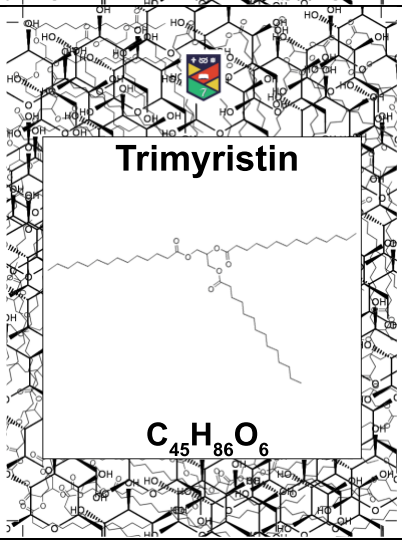

Alanine is one of 20 amino acids. Amino acids are monomers from which proteins are made. They contain an amino group (NH2), a carboxylic acid (COOH) and a variable group (R), which is a carbon containing chain. Each of the 20 amino acids have different R groups. Amino

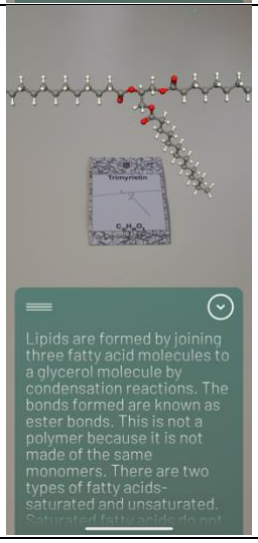

Adenosine Triphosphate
(ATP)
adenine
ribose
3 phosphate groups
P
P
P
$C_{10}H_{16}N_5O_{13}P_3$

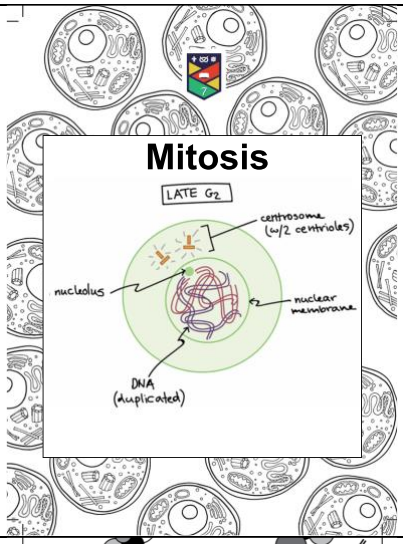

Adenosine Triphosphate (ATP) is a nucleotide derivative that consists of adenine, a ribose molecule and three phosphate groups. Energy is released when the third phosphate group is removed through a hydrolysis reaction catalysed by ATP hydrolase. The result of this reaction is ADP and a

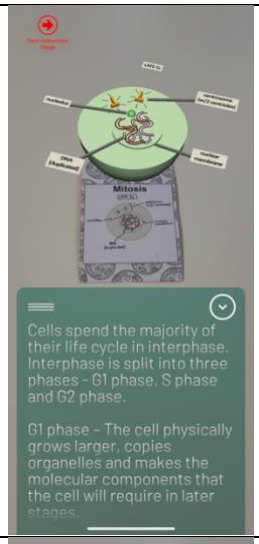

Phospholipid
Hydrophilic head
Hydrophobic tails
Phosphate
Glycerol
Saturated fatty acid
Unsaturated fatty acid

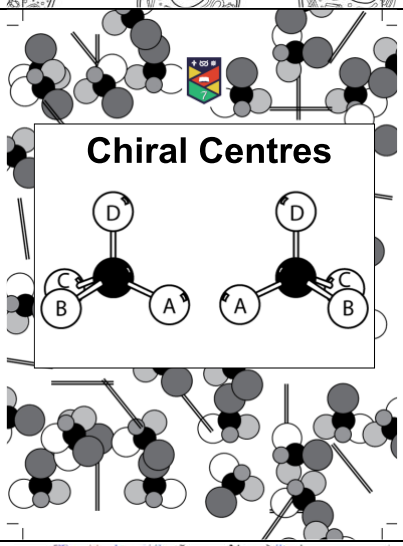

Phospholipids are made up of one glycerol molecule, two fatty acids and a phosphate-containing group. The phosphate head is hydrophilic and the fatty acid tails are hydrophobic. As a result phospholipids form micelles when they come into contact with water - the heads on the

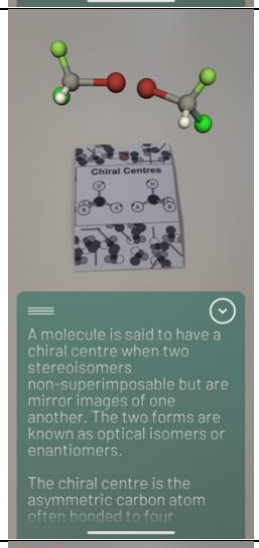

Trimyristin
$C_{45}H_{86}O_6$

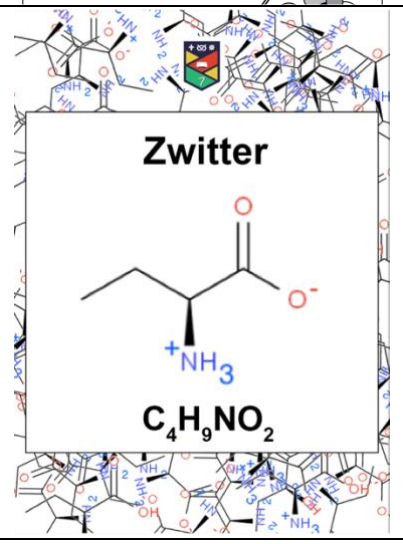

Lipids are formed by joining three fatty acid molecules to a glycerol molecule by condensation reactions. The bonds formed are known as ester bonds. This is not a polymer because it is not made of the same monomers. There are two types of fatty acids- saturated and unsaturated.

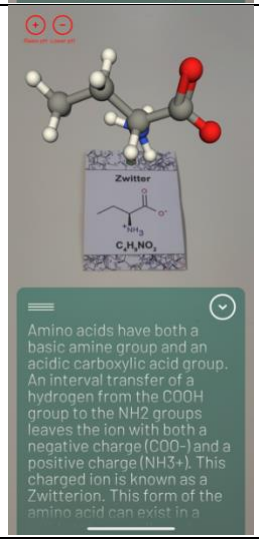

Mitosis
LATE G2
centrosome (4/2 centrioles)
nucleolus
nuclear membrane
DNA (duplicated)

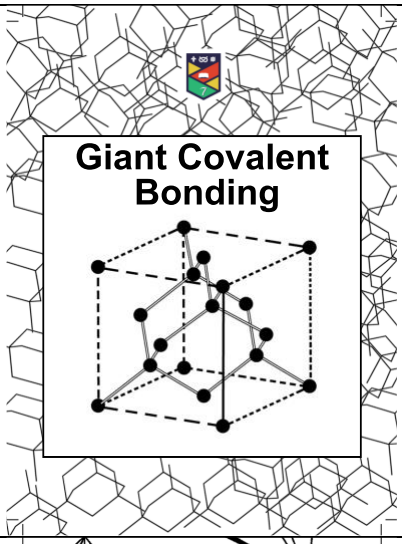

Mitosis
Cells spend the majority of their life cycle in interphase. Interphase is split into three phases - G1 phase, S phase and G2 phase.
G1 phase – The cell physically grows larger, copies organelles and makes the molecular components that the cell will require in later stages.

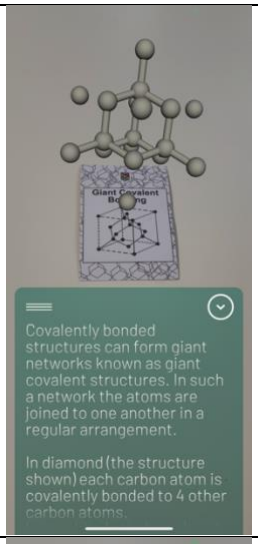

Chiral Centres
D
C
B
A
D
C
A
B

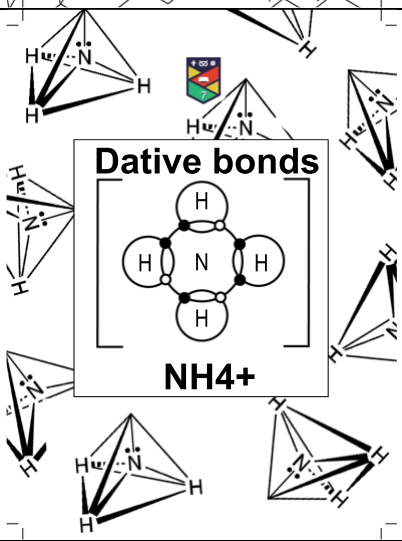

Chiral Centres
A molecule is said to have a chiral centre when two stereoisomers non-superimposable but are mirror images of one another. The two forms are known as optical isomers or enantiomers.
The chiral centre is the asymmetric carbon atom often bonded to four

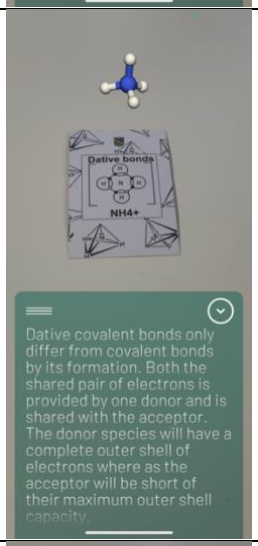

Zwitter
O
O-
+NH3
C4H9NO2

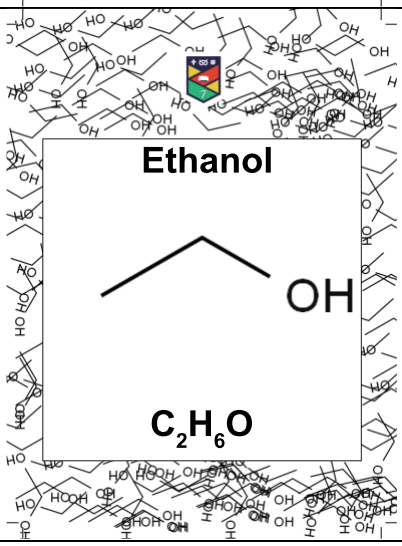

Zwitter
C4H9NO2
Amino acids have both a basic amine group and an acidic carboxylic acid group. An interval transfer of a hydrogen from the COOH group to the NH2 groups leaves the ion with both a negative charge (COO-) and a positive charge (NH3+). This charged ion is known as a Zwitterion. This form of the amino acid can exist in a

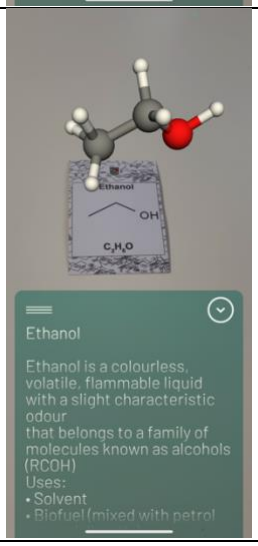

Giant Covalent Bonding

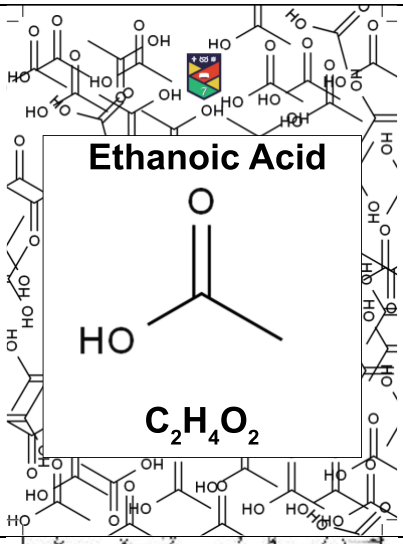

Covalently bonded structures can form giant networks known as giant covalent structures. In such a network the atoms are joined to one another in a regular arrangement.
In diamond (the structure shown) each carbon atom is covalently bonded to 4 other carbon atoms.


Dative bonds
NH4+

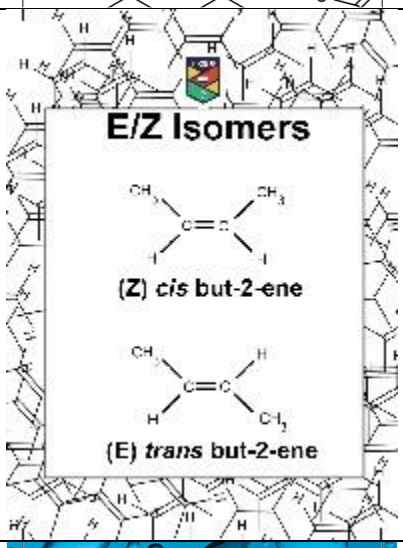

Dative covalent bonds only differ from covalent bonds by its formation. Both the shared pair of electrons is provided by one donor and is shared with the acceptor. The donor species will have a complete outer shell of electrons where as the acceptor will be short of their maximum outer shell capacity.

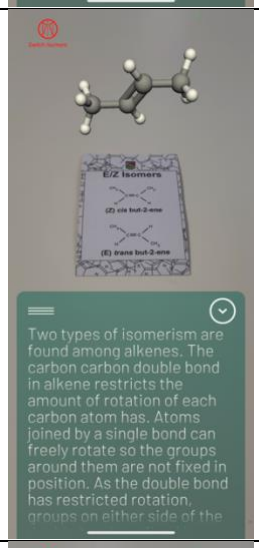

Ethanol
OH
C2H6O

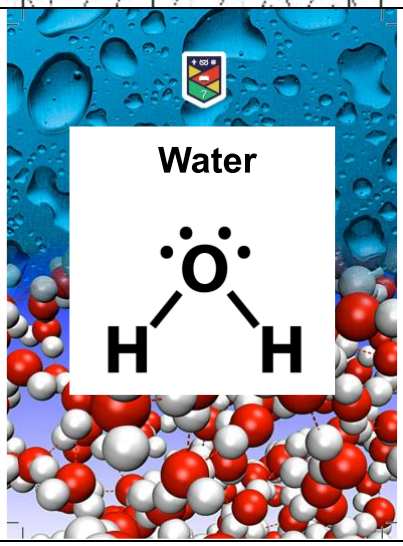

Ethanol
Ethanol is a colourless, volatile, flammable liquid with a slight characteristic odour that belongs to a family of molecules known as alcohols (ROH)
Uses:
• Solvent
• Biofuel (mixed with petrol


Ethanoic Acid
HO
$C_2H_4O_2$

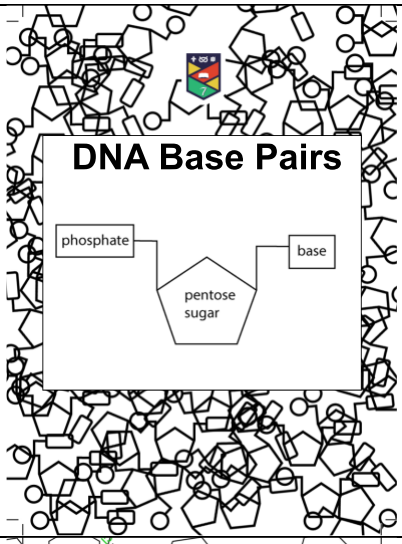

Ethanoic Acid
Ethanoic acid belongs to a group of molecules known as carboxylic (RCOOH). Has weak acidic properties (pH 2-3) and reacts with alcohols to form esters.
Uses:
• Vinegar/ food additive
• Production of esters
• Solvent
• Medical uses as an

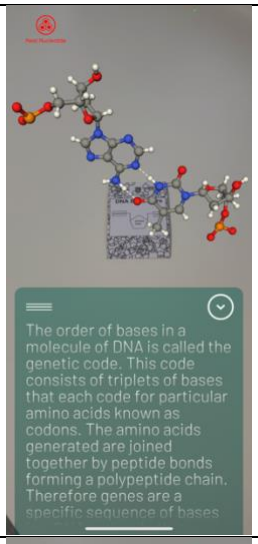

E/Z Isomers
(Z) *cis* but-2-ene
(E) *trans* but-2-ene

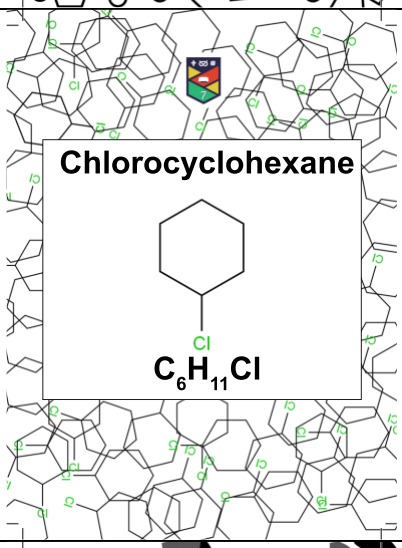

E/Z Isomers
Two types of isomerism are found among alkenes. The carbon carbon double bond in alkene restricts the amount of rotation of each carbon atom has. Atoms joined by a single bond can freely rotate so the groups around them are not fixed in position. As the double bond has restricted rotation, groups on either side of the


Water
H
O
H

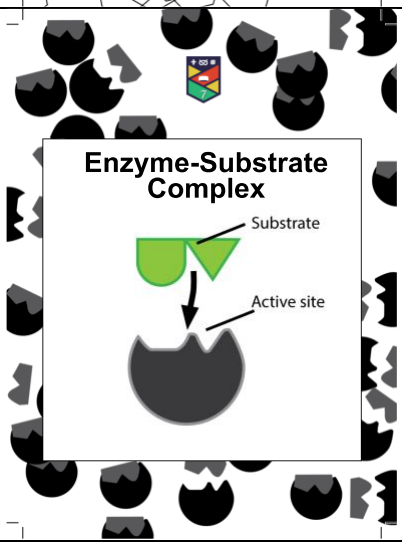

Water
Water is a polar molecule due to its uneven distribution of charge. The hydrogen atoms carry more of a positive charge than the oxygen atom resulting in one end of the molecule carrying a more positive charge than the other.
The 3D model displays the arrangement of the two-long


DNA Base Pairs
phosphate
base
pentose sugar


The order of bases in a molecule of DNA is called the genetic code. This code consists of triplets of bases that each code for particular amino acids known as codons. The amino acids generated are joined together by peptide bonds forming a polypeptide chain. Therefore genes are a specific sequence of bases


Chlorocyclohexane
Cl
$C_6H_{11}Cl$


Nuclear magnetic resonance spectrometers effectively "counts the number of C or H atoms in a molecule and displays the value by the number of different signals generated.
"Every Carbon of hydrogen atom in given a molecule that has a different environment will produce a


Enzyme-Substrate Complex
Substrate
Active site


Enzymes are biological catalysts that increase the rate of reactions by lowering the activation energy required for the reactions they catalyse. The active site of the enzyme is the location where the substrate(s) temporarily binds to form a complex. When the substrate binds to the active site, the structure of the

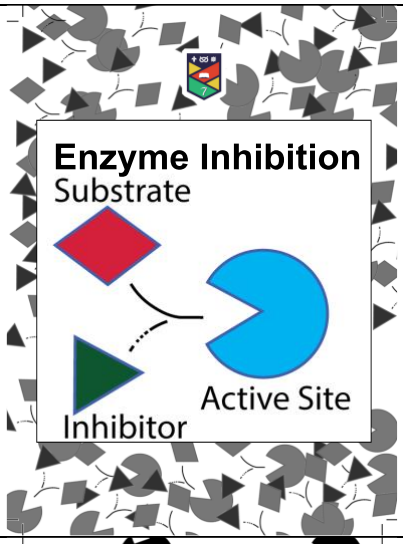
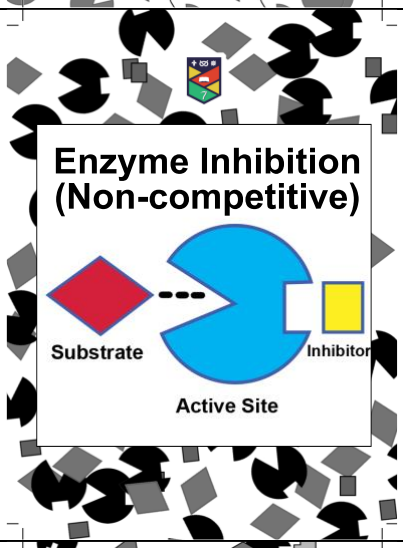
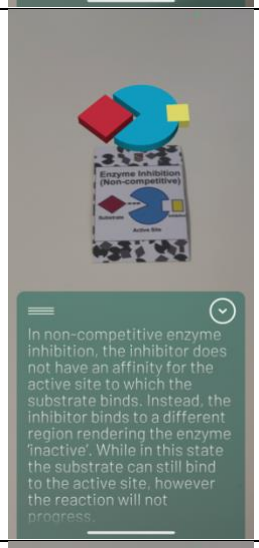
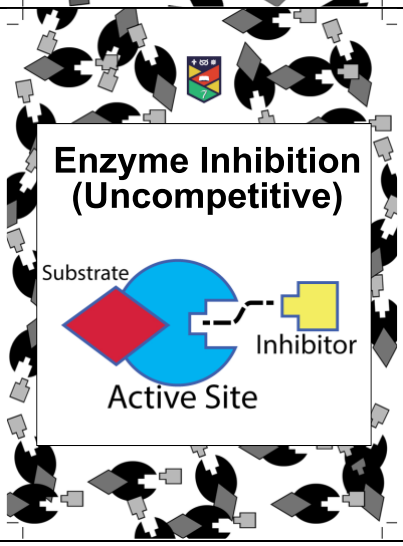
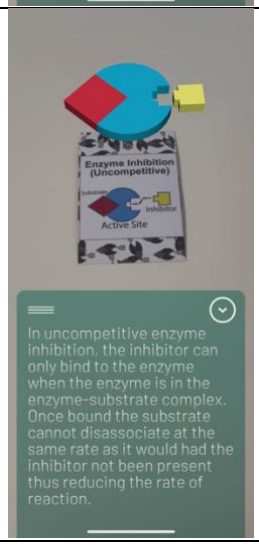
	
	
	

Table 6.10 details all 24 Pharma Compound card target images and the associated on-screen 3D models

6.10 Chapter Summary

The chapter detailed how the Pharma Compound AR tool was conceived and developed. The process began by first surveying chemistry and biology year 13 students, year 12 biology and chemistry tutors, as well as stage 3 MPharm students, and stage 2 MPharm tutors to understand what particular topics and aspects of year 12 biology and chemistry courses and stage 2 MPharm course perceived to be difficult to learn. The findings from this survey informed and contributed to the topics included in the final rendition of the Pharma Compounds tool. This chapter also detailed the process by which the 3D models were generated and imported into the mobile app, as well as the functionality of the AR system. The development process resulted in Pharma Compounds, a new mobile-based educational augmented reality application with 24 physical target image cards based on the earlier PharmaCards Keele AR systems.

7 Year 12 and Undergraduate Stage 2 Quantitative Quiz Results

7.1 Introduction

One of the main objectives of this study was to establish whether using the AR Pharma Compound educational tool improved participants' knowledge (section 3.2). Participants were asked to complete a set of pre- and post-intervention MCQ quizzes to achieve this objective. The content of both sets of quizzes were based on the academic content of the intervention tool. The experimental hypothesis stated that year 12 sixth form and undergraduate Stage 2 students would show improved performance in the post-quiz compared to the pre-quiz (Chapter 3.2). This chapter presents the quantitative pre- and post-quiz results for year 12 sixth form and Stage 2 MPharm students. Section 7.2 displays the response rates and demographic data for year 12 sixth form quiz responses. The results of the sixth form quizzes are reported in section 7.3. Section 7.4.

7.2 Year 12 Quiz Response Rates and Demographic Data

In total, 65 Year 12 biology and Chemistry students initially consented to participate; 51 completed the pre-quiz, and 22 completed the post-quiz after the intervention period. The response rates and demographic breakdown of the Year 12 participants are displayed below in Table 7.1. The response rates were calculated to compare the number of participants who completed the pre-quiz to those who completed the post-quiz.

		Consented	Pre-Quiz	Post-Quiz
Total Number of Students (RR%)		65	51(76%)	22 (34%)
Gender	Male	15	13 (25%)	6 (27%)
	Female	45	34 (67%)	15 (68%)
	Prefer not to say	5	4 (8%)	1 (5%)
Age	16-17	57	43 (84%)	20 (91%)
	18-19	8	7 (14%)	2 (9%)
	19+	0	0 (0%)	0 (0%)
	Prefer not to say	1	0 (0%)	0 (0%)
Country	UK	17	17 (33%)	14 (66%)
	Kenya	48	34 (66%)	8 (37%)
Type of School	Independent	65	51 (100%)	22 (100%)
Subject	Biology	13	11 (22%)	4 (18%)
	Chemistry	10	9 (18%)	4 (18%)
	Biology and chemistry	42	31 (61%)	14 (64%)

Table 7.1 displays the response rates and demographics for year 12 biology and chemistry student pre- and post-quizzes

A decline in the rate of responses was observed between the pre- and post-intervention quizzes. The observed decline was uniform amongst both male and female participants. The response rates for the pre- and post-intervention quizzes were 76% and 34%, respectively; this was calculated in relation to the number of students who initially consented to participate. Data collected from all participants are presented in table 7.1. This includes data from participants who completed either the pre- or post-intervention quiz and those who had completed both. Of the 22 students who completed the post-quiz, 18 (81.8%) completed the pre-quiz - 14 students completed the pre- and post-biology quizzes, and 15 students completed the chemistry pre- and post-quizzes. 11 of those 14 participants were enrolled on both biology and chemistry courses, three were enrolled on only a biology course and four were enrolled solely on a chemistry course. Four students who completed the post-quiz had not completed the pre-quiz (section 6.8.2).

Table 7.1 shows that most participants who completed either the pre- or post-intervention quiz were female (67% and 68%, respectively) and aged between 16 and 17. All students

who participated in both quizzes attended independent Sixth Form schools, with two-thirds of pre-quiz responses completed by students who studied in Kenya (66%). Students from the United Kingdom completed one-third of the pre-quizzes. This distribution was then reversed in the post-intervention quiz responses. Two-thirds of the responses were from students from the United Kingdom, and the remaining third was from Kenya. The majority of respondents for both the pre- and post-intervention quizzes were aged between 16-17 (84% and 91%, respectively). 61% of students who completed the pre-quiz were enrolled in chemistry and biology sixth form courses. 22% were enrolled on only biology courses, and 18% studied only chemistry. These proportions remained relatively the same concerning the post-intervention quiz demographics – 64% were enrolled on both biology and chemistry courses, and 18% were enrolled on a biology or chemistry course. 55% of participants who completed the pre-quiz had been involved in research previously; this figure was the same for those who completed the post-quiz.

7.3 Year 12 Quiz Results

7.3.1 Descriptive Statistics

Knowledge scores for the pre- and post-intervention quizzes were measured for biology and chemistry students and detailed in table 7.2. Participants were only required to answer the quiz that related to the course(s) they were enrolled on – biology students were only required to answer the biology quiz (11 MCQs), chemistry students were required to answer the chemistry quiz (10 MCQs) and students enrolled on both were required to answer both quizzes (21 MCQs). A total of 42 students completed the biology pre-quiz questions, and 40 completed the chemistry pre-quiz questions. As detailed in Table 7.1, the post-intervention response rates fell. As a result, 18 students completed the biology post-quiz, and 18

completed the chemistry post-quiz (14 were enrolled on both courses and completed both quizzes). 18 of the 22 students who completed the post-intervention quiz also completed the pre-intervention quiz.

		Number of Correct Quiz Questions			
		Mean (SD)	**Median**	**Mode**	**Range**
Biology Questions (11 MCQs)	Pre-Quiz	7.26 (1.93)	7	7	3-11
	Post Quiz	7.28 (1.57)	7.5	8	4-10
Chemistry Questions (10 MCQs)	Pre-Quiz	6.42 (1.36)	6	6	4-10
	Post-Quiz	7.11 (1.70)	7	9	4-9

Table 7.2 Displays the descriptive statistics relating to the number of correctly answered biology and chemistry pre- and post-quiz questions by sixth form students.

The baseline scores for the biology quiz had an almost identical mean score compared to the post-intervention scores (7.26 vs 7.28). However, the baseline mean score for the chemistry pre-quiz was slightly lower than the mean score recorded for the post-intervention quiz (6.43 vs 7.00). Both sets of quiz questions had a wide range of total correct responses. The biology post-intervention scores ranged from 4 to 10 correct answers. A similar range was evident in the chemistry post-quiz scores, with 4 to 9 correct answers. A slight increase was apparent when comparing the pre-and post-quiz median and mode scores for each set of quizzes. The median and mode scores for the biology quiz increased from 7 and 7 to 7.5 and 8, respectively. The median and mode scores for the chemistry quiz increased from 6 and 6 to 7 and 9, respectively.

7.3.2 Sixth Form Student Dependent and Independent T-Test

Scores achieved by participants who completed both the pre-and post-quizzes (biology N=14 and chemistry N=15) were included in the statistical two tailed dependent t-test to compare the mean scores before and after using the AR tool. The analysis found that there

were no significant differences in the performance of year 12 students between the pre- and post-biology ($t_{(14)}$ = -0.806, p>0.05) and chemistry ($t_{(15)}$ = -1.057, p>0.05) intervention quizzes. Due to a lack of significant differences between the pre- and post-quiz scores, the experimental hypothesis was not accepted – The knowledge of Year 12 biology and chemistry students and Stage 2 MPharm students will improve with the use of the Pharma Compound cards educational tool (Chapter 3.2).

Two tailed independent t-tests were used to identify if there were any statistically significant differences between quiz scores and gender, country of study, or subject studied. Only knowledge improvement scores greater than 0 were used in this analysis. Some participants recorded lower scores in the post-quiz and would have a negative knowledge change. As a result, only results that showed improvement were used. Both the biology and chemistry quiz scores were combined, and the analysis was performed on the data set as a whole. The quiz scores were combined as only the positive changes in quiz scores were analysed, and individually the number of cases would not be enough to perform a t-test or ANOVA tests. After the adjustments, no more than two categories were occupied, and therefore, independent t-tests were carried out in place of the ANOVA test, as discussed in Chapter 5.8.2. The two- tailed independent t-test found no significant differences between gender ($t_{(12)}$ = -0.402, p>0.05), country of study ($t_{(12)}$ = 0.000, p>0.05), or subject topics of the quiz (biology or chemistry) ($t_{(12)}$ = 0.352, p>0.05) and quiz scores improvement. The test was not performed on the 'type of school' variable as all participants attended a private/independent institution.

7.3.3 Performance on Individual Questions

The number and percentage of students who correctly answered each question for the pre- and post-biology and chemistry quizzes are displayed in tables 7.3 and 7.4, respectively (Appendices 40 and 41). The scores of the biology students in the post-quiz MCQs depicted an overall decrease in performance compared to the pre-quiz. However, the chemistry students' knowledge showed an overall improvement in the post-quiz compared to the pre-quiz.

Tables 7.3 and 7.4 also include the percentage change of each correctly answered question across the pre- and post-quizzes. The percentage of students who correctly answered biology quiz questions were found to have been >10% after the intervention period in questions based on the following topic areas: stages of mitosis (Q2), enzyme activity (Q6), polysaccharide bonding (Q8), and properties of water (Q10). There were no positive percentage changes of correctly answered questions <10%. The same analysis was applied to the quiz results of the chemistry students and revealed that there was a >10% increase in the percentage of participants who correctly answered quiz questions based on the following three subject areas: structural isomerism (Q4), chiral centres (Q9) and formation of an ester (Q10). The remaining questions with a positive percentage change in correctly answered questions had differences of <10%. Those topic areas were; structures of fatty acids (Q3), dative bonding (Q5), shapes of chemical structures (Q6) and types of chemical compounds (Q8).

There were questions on the biology and chemistry quizzes where knowledge seemed to have worsened and yielded negative percentage changes. The number of biology students

who correctly answered quiz questions fell by >10% in questions that focused on polysaccharide formation (Q1), structures of polysaccharides (Q3), metaphase cell activity (Q7), DNA nucleotides (Q9) and phospholipid liposome formation (Q10). The remaining two subject areas, stages of mitosis (Q4) and formation of triglycerides (Q5), had a negative percentage change of <10%. Concerning the chemistry MCQ quizzes, the degree to which correctly answered questions decreased was smaller than in the biology quiz. No subject areas had a negative percentage difference greater than >10%. Q1 (polysaccharide formation), Q2 (formation of triglycerides) and Q7 (types of chemical bonds) all had a negative percentage change of <10%.

Question Number	Biology Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	37 (88.1)	13 (72.2)	-15.9
2	Stages of mitosis	34 (81.0)	17 (94.4)	13.4
3	Structure of simple polysaccharides	24 (57.1)	7 (38.9)	-18.2
4	Stage of mitosis	39 (92.9)	15 (83.3)	-9.6
5	Formation of triglycerides	36 (85.7)	15 (83.3)	-2.4
6	Enzyme activity	16 (38.1)	10 (55.6)	17.5
7	Metaphase cell activity	31 (73.8)	8 (44.4)	-29.4
8	Polysaccharide bonding	33 (78.6)	17 (94.4)	15.8
9	DNA nucleotide	22 (52.4)	7 (38.9)	-13.5
10	Phospholipid liposome formation	17 (40.5)	5 (27.8)	-12.7
11	Properties of water molecule	16 (38.1)	17 (94.4)	56.3

Table 7.3 displays the number and percentage of students who correctly answered each biology quiz question. The table also shows the percentage changes between the pre- and post-quizzes. A total of 42 participants answered the pre-quiz, and 18 participants answered the post-quiz.

Question Number	Chemistry Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	28 (70.0)	12 (66.7)	-3.3
2	Formation of triglycerides	36 (90.0)	15 (83.3)	-6.7
3	Structure of fatty acids	15 (37.5)	7 (38.9)	1.5
4	Structural Isomerism	14 (35.0)	9 (50.0)	15.0
5	Dative bonding	20 (50.0)	10 (55.6)	5.6
6	Shapes of chemical structures	31 (77.5)	14 (77.8)	0.3
7	Types of chemical bonds	38 (95.0)	17 (94.4)	-0.6
8	Types of chemical compounds	35 (87.5)	17 (94.4)	6.9
9	Chiral Centres	21 (52.5)	13 (71.2)	18.7
10	Formation of an ester	19 (47.5)	12 (66.7)	19.2

Table 7.4 displays the number and percentage of students who correctly answered each chemistry quiz question. The table also shows the percentage changes between the pre- and post-quizzes. A total of 40 participants answered the pre-quiz, and 18 answered the post-quiz.

Tables 7.5 (biology) and 7.6 (chemistry) below display the pre- and post- data of sixth-form participants who completed both the pre- and post-intervention quizzes. As detailed in section 7.2, a total of 14 participants complete both pre-and post- biology quizzes. With respect to chemistry students, 15 participants completed both pre- and post-quizzes.

Question Number	Biology Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	11 (78.6)	13 (92.9)	14.3
2	Stages of mitosis	12 (85.7)	13 (92.9)	7.2
3	Structure of simple polysaccharides	7 (50.0)	8 (57.1)	7.1
4	Stage of mitosis	12 (85.7)	13 (92.9)	7.2
5	Formation of triglycerides	14 (100.0)	8 (57.1)	-42.9
6	Enzyme activity	3 (21.4)	8 (57.1)	35.7
7	Metaphase cell activity	10 (71.4)	7 (50.0)	-21.4
8	Polysaccharide bonding	12 (85.7)	14 (100.0)	14.3
9	DNA nucleotide	7 (50.0)	4 (28.6)	-21.4
10	Phospholipid liposome formation	5 (35.7)	3 (21.4)	-14.4
11	Properties of water molecule	9 (64.2)	14 (100.0)	35.8

Table 7.5 displays the number and percentage of students who correctly answered each biology quiz question. The table also shows the percentage changes between the pre- and post-quizzes. These are the results of participants who answered both the pre- and post-quizzes.

Question Number	Chemistry Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	12 (80.0)	12 (80.0)	0.0
2	Formation of triglycerides	14 (93.3)	13 (86.7)	-6.6
3	Structure of fatty acids	7 (46.7)	7 (46.7)	0.0
4	Structural Isomerism	8 (53.3)	7 (46.7)	-6.6
5	Dative bonding	8 (53.3)	8 (53.3)	0.0
6	Shapes of chemical structures	11 (73.3)	13 (86.7)	13.4
7	Types of chemical bonds	15 (100.0)	14 (93.3)	-6.7
8	Types of chemical compounds	13 (86.7)	14 (93.3)	6.6
9	Chiral Centres	8 (53.3)	11 (73.3)	20.0
10	Formation of an ester	9 (60.0)	9 (60.0)	0.0

Table 7.6 displays the number and percentage of students who correctly answered each chemistry quiz question. The table also shows the percentage changes between the pre- and post-quizzes. These are the results of participants who answered both the pre- and post-quizzes.

The results indicate that sixth form chemistry students showed greater instances of improved performance on quiz topics compared to the sixth form biology students (table 7.3 and 7.4). When looking at the results of participants who completed both the pre- and post-quizzes the trend reverts (table 7.5 and 7.6). Sixth form biology students had an improved performance on seven of the ten questions. Improvements were seen in three of the ten chemistry question topics with four question topics showing no changes at all.

7.3.4 Sixth Form Student Timestamp Analysis

The date and time of each completed pre- and post-quiz were recorded and analysed to understand the period participants may have used the Pharma Compounds AR tool. The design of this study intended for there to be an intervention period of at least three months. Most students completed the post-intervention quizzes seven months after completing the pre-quizzes (43% chemistry and 40% biology students) due to delays and disturbances caused by the COVID-19 pandemic. The most extended period between the completion of the two biology quizzes was ten months (14%); concerning the chemistry quizzes, the longest intervention period was recorded to have been seven months (40%).

The shortest duration between the pre- and post-quizzes of both subjects was recorded as two months (7% of biology participants and 27% of chemistry participants). The mean intervention period for the biology quizzes was 5.93 weeks, whereas the mean chemistry quizzes intervention period was 4.33 weeks.

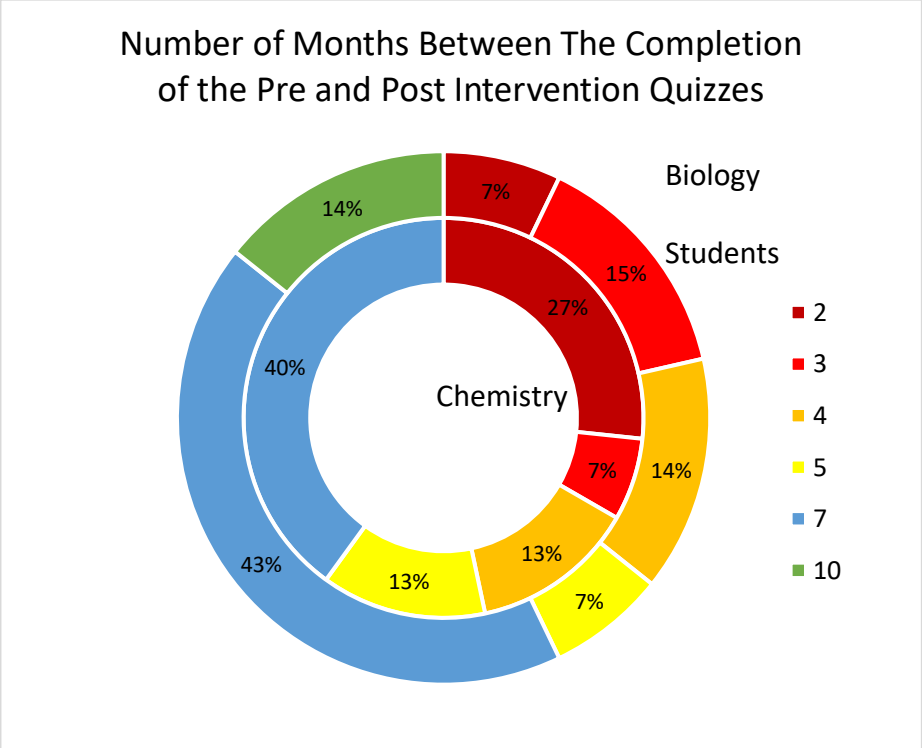


Figure 7.1 displays the percentage breakdown of the intervention period between the pre- and post-quizzes of biology (outer ring) and chemistry (inner ring) sixth form students

7.4 Undergraduate Students Response Rates and Demographics

A total of 72 stage 2 Keele Undergraduate MPharm students consented to participate in this study. Of these students, 64 completed the pre-intervention quiz and 31 completed the post-intervention quiz. The response rates and demographic breakdown can be seen in table 7.7.

		Consented	Pre-Quiz	Post-Quiz
Total Number of Students (RR%)		72	64 (89%)	31 (43%)
Gender	Male	20	18 (28%)	10 (32%)
	Female	48	42 (66%)	21 (68%)
	Prefer not to say	5	4 (6%)	0 (0%)
Age	18-21	56	48 (75%)	24 (77%)
	22-25	8	8 (13%)	5 (16%)
	25+	4	4 (6%)	2 (7%)
	Prefer not to say	4	4 (6%)	0 (0%)
Type of Student	Domestic	64	64 (88%)	27 (87%)
	International	4	4 (6%)	4 (13%)
	Prefer not to say	4	6 (6%)	0 (0%)

Table 7.7 displays the response rates for the Undergraduate MPharm students' pre- and post-quizzes.

Similar to the response rates seen in the year 12 student cohort, the number of students who completed the post-intervention quiz declined compared to that of the pre-quiz. The response rate fell from 89% in the pre-quiz to 43% in the post-intervention quiz – these rates are about the total number of students who consented to participate. As with the Sixth form participants, the presented data included data collected from students who had completed either the pre- or post-intervention quiz and those who had completed both. The response rate for students who completed both the pre- and post-intervention quizzes was 43%. 100% of the students who completed the post-quiz had also completed the pre-intervention quiz (section 6.8.2).

Table 7.7 illustrates that most undergraduate MPharm participants who completed the pre-intervention quiz were female (66%). The female response rate for the post-intervention quiz was similar to that of the pre-quiz (68%). 75% of pre-quiz participants were aged between 18-21, and a similar percentage of responses to the post-quiz were from this same age group of participants (77%). The proportion of domestic student participants who completed either the pre- or post-quizzes was very similar, 88% and 87% in the pre- and post-quizzes, respectively. Finally, the proportions of students who had claimed to have or

to have not participated in a research project previously were also very similar for both the pre- and post-intervention questionnaires (43% and 41%, respectively).

7.5 Undergraduate MPharm Quiz Results

7.5.1 Descriptive Statistics

The knowledge scores from the pre- and post-intervention quizzes were measured and presented in table 7.8. Unlike the sixth form pre- and post-quizzes, the undergraduate quizzes were not separated by subject – there were a series of 19 MCQs (different questions on pre and post). A total of 64 undergraduate MPharm students completed the pre-intervention quiz, with 31 continuing to complete the post-quiz.

		Number of Questions Answered Correctly			
		Mean (SD)	**Median**	**Mode**	**Range**
MPharm Questions (19 MCQs)	Pre-Quiz	10.69 (2.66)	11	13	3-16
	Post-Quiz	11.00 (3.52)	11	10, 13, 14	2-16

Table 7.8 displays the descriptive statistics relating to the number of quiz questions correctly answered by Undergraduate MPharm Participants

The mean pre-intervention quiz score was almost identical to the mean post-intervention quiz score, with less than 0.5 separating the two means (10.69 vs 11.00). The range of scores in both the pre- and post-quizzes was very similar. The maximum scores in both quizzes were 16, with the lowest scores being 3 and 2, respectively. The pre-quiz had a median score of 11, with a mode of 13. Similarly, the post-intervention quiz had a median score of 11. However, three sets of scores appeared most often in the post-quiz – 10, 13 and 14.

7.5.2 Undergraduate MPharm Student Dependent T-test, Independent T-tests, and ANOVA

As with the results gathered from the sixth form students, a two tailed dependent t-test was performed on the results collected from the undergraduate MPharm students who had completed both the pre- and post-quizzes (N=31). Analysis showed there was no significant difference between the mean score of undergraduate MPharm students on the post-intervention quiz when compared to their performance on the pre-quiz ($t_{(31)}$=-0.94, p>0.05). The lack of significance between the differences in mean quiz scores (pre-quiz = 10.94, post-quiz = 11.00) meant that the experimental hypothesis was not accepted - The knowledge of Stage 2 MPharm students will improve with the use of the Pharma Compound cards educational tool (Chapter 3.2). Similar to the findings of sixth form student results, it can be said that the use of the Pharma Compounds AR tool may not improve the knowledge of MPharm students.

Chapter 5.8.2 detailed that independent t-tests and an ANOVA test were appropriate to highlight any statistically significant differences between improvements in knowledge and the independent variables – gender, type of students, and age. Only knowledge improvement scores greater than 0 were included in these statistical tests. Similar to the Sixth Form students, a number of MPharm participants (10) recorded a lower score in the post-quiz resulting in a negative change in knowledge; therefore, only positive changes were included. Again, after the adjustments, only two subgroups were occupied within the gender and type of student independent variables. The age variable, however, had more than two categories occupied; thus, the ANOVA test was performed. The two tailed independent t-test found that there were no significant differences between gender ($t_{(18)}$ =

1.291, p>0.05) or type of student (domestic or international) ($t_{(18)}$ = -0.532, p>0.05) and knowledge improvement scores. The ANOVA test found that there were no significant differences between the means of any pairing of the three different age categories (18-21, 22-25 and 25+ years) $F_{(2, 17)}$ = 0.533, p>0.05). Therefore, the tool did not significantly improve the performance of one age group over the others in the post-quiz.

7.5.3 Performance on Individual Questions

The individual questions on the pre- and post-quizzes were analysed for correctness and are tabulated in table 7.7. When comparing each pre-and post- MCQ, 11 of the 19 questions resulted in positive percentage changes, whereas the remaining eight had negative changes of varying magnitudes.

A positive percentage change of >10% was calculated in the following five subject areas: polysaccharide formation (Q1), polysaccharide bonding (Q5), phospholipid liposome formation (Q7), the structure of fatty acids (Q9) and shapes of chemical structures (Q12). An additional six questions showed positive percentage changes of <10%. The topics of those questions involved enzyme activity (Q4), structural isomerism (Q10), types of chemical compounds (Q14), zwitter ions and pKa (Q15) and chiral centres (Q18).

As with the percentage changes seen in the sixth form students' quiz results, there too were negative percentage changes between the MPharm pre- and post-quiz scores. Stages of mitosis (Q2), formation of triglycerides (Q3) and carbon 13 NMR (Q13 and Q17) subject areas all revealed negative percentage changes of >10%. The remaining topics: DNA nucleotides (Q6), properties of water molecules (Q8), dative bonding (Q11) and structural

isomerism (Q19), all had a negative percentage change of <10% between pre- and post-intervention quizzes.

Question Number	MPharm Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	33 (51.6)	20 (64.5)	12.9
2	Stages of mitosis	54 (84.4)	21 (67.7)	-16.7
3	Formation of triglycerides	49 (76.6)	20 (64.5)	-12.1
4	Enzyme activity	16 (25.0)	8 (25.8)	0.8
5	Polysaccharide bonding	46 (71.9)	27 (87.1)	15.2
6	DNA nucleotides	29 (45.3)	14 (45.2)	-0.1
7	Phospholipid liposome formation	12 (18.8)	14 (45.2)	26.4
8	Properties of water molecule	55 (85.9)	25 (80.6)	-5.3
9	Structure of fatty acids	22 (34.4)	17 (54.8)	20.4
10	Structural Isomerism	35 (54.7)	17 (54.8)	0.1
11	Dative bonding	28 (43.8)	11 (35.5)	-8.3
12	Shapes of chemical structures	43 (67.2)	25 (80.6)	13.4
13	Carbon 13 NMR	48 (75.0)	17 (54.8)	-20.2
14	Types of chemical compounds	53 (82.9)	28 (90.3)	7.4
15	Zwitter ions and pKa	11 (17.2)	6 (19.4)	2.2
16	Chiral Centres	45 (70.3)	23 (74.2)	3.9
17	Carbon 13 NMR	43 (67.2)	17 (54.8)	-12.4
18	Formation of an ester	31 (48.4)	17 (54.8)	6.4
19	Structural Isomerism	31 (48.4)	14 (45.2)	-3.2

Table 7.9 displays the number and percentage of undergraduate students who correctly answered each MCQ. The table also shows the percentage change of correct responses between the pre- and post-quiz MCQs.

The performance of participants who completed both the pre- and post-intervention for each topic is tabulated in table 7.10. A total of 31 students completed the pre- and the post-intervention quizzes.

Question Number	MPharm Question Description	Number of Correct Answers (%)		Percentage Change (%)
		Pre-Quiz	Post-Quiz	
1	Polysaccharide Formation	14 (45.2)	20 (64.5)	19.3
2	Stages of mitosis	25 (80.6)	21 (67.7)	-12.9
3	Formation of triglycerides	23 (74.2)	20 (64.5)	-9.7
4	Enzyme activity	7 (22.6)	8 (25.8.)	3.2
5	Polysaccharide bonding	23 (74.2)	27 (87.1)	12.9
6	DNA nucleotides	13 (41.9)	14 (45.2)	3.3
7	Phospholipid liposome formation	7 (22.6)	15 (48.4)	25.8
8	Properties of water molecule	28 (90.3)	26 (83.9)	-6.4
9	Structure of fatty acids	10 (32.3)	17 (54.8)	22.5
10	Structural Isomerism	19 (61.3)	17 (54.8)	-6.5
11	Dative bonding	11 (35.5)	11 (35.5.)	0.0
12	Shapes of chemical structures	22 (71.0)	25 (80.6)	9.6
13	Carbon 13 NMR	25 (80.6)	17 (54.8)	-25.8
14	Types of chemical compounds	28 (90.3)	28 (90.3)	0.0
15	Zwitter ions and pKa	2 (6.5)	6 (19.4.)	12.9
16	Chiral Centres	25 (80.6)	23 (74.2)	-6.4
17	Carbon 13 NMR	21 (67.7)	17 (54.8)	-12.9
18	Formation of an ester	16 (51.6.)	17 (54.8)	3.2
19	Structural Isomerism	18 (58.1.)	14 (45.2)	-12.9

Table 7.10 displays the number and percentage of undergraduate students who correctly answered each quiz question. The table also shows the percentage changes between the correctly answered pre- and post-quizzes. These as the results of participants who answered both the pre- and post-quizzes.

7.5.4 Undergraduate MPharm Timestamp Analysis

The timestamp data collected for pre- and post-quizzes were analysed to determine the distribution between undergraduate students. As with the sixth form student cohort, the intervention period was intended to be a minimum of three months. The majority of students did, in fact have the desired intervention period (53%). 17% of students completed the post-intervention quiz two months after completing the pre-quiz. The most extended duration between the completion of the pre-and post-intervention quizzes observed in the MPharm students was four months (30%).

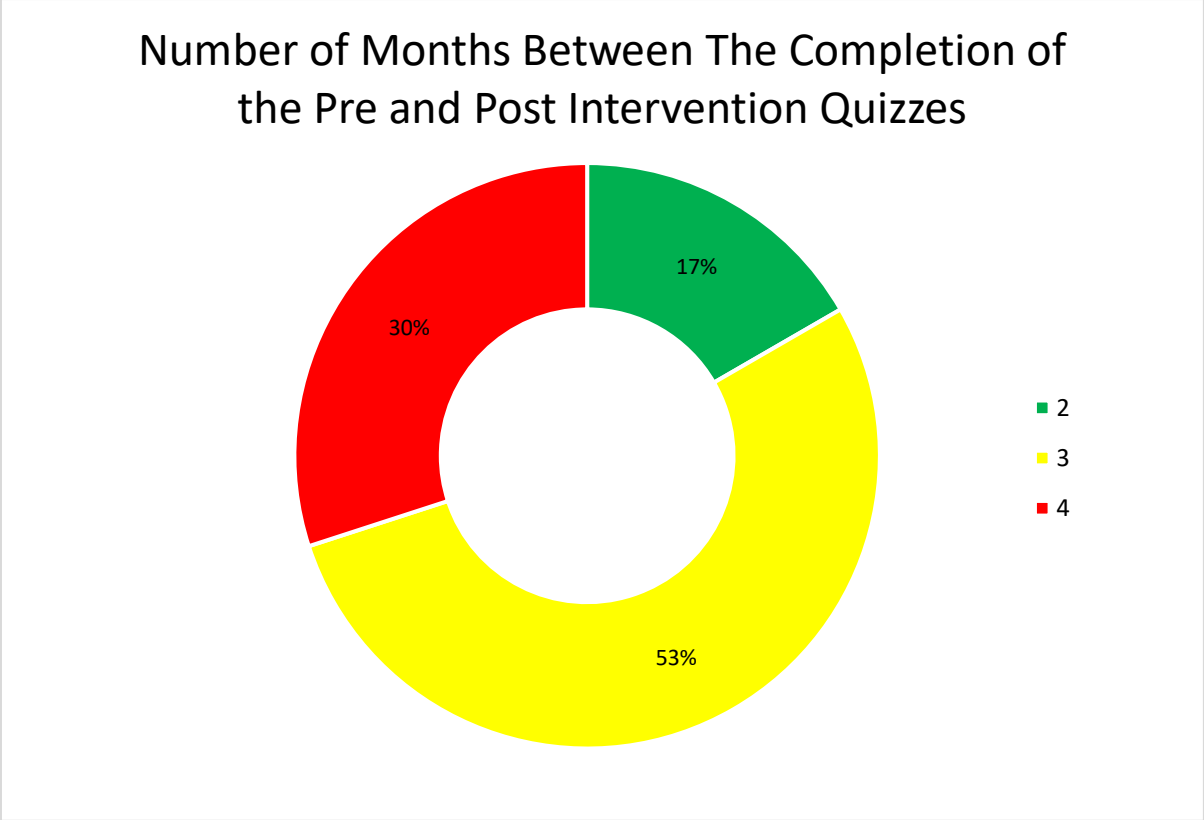


Figure 7.2 displays the percentage breakdown of the intervention period between the pre- and post-quizzes of undergraduate MPharm students

7.6 Chapter Discussion

One of the objectives of this research was to establish if the Pharma Compound AR tool would improve the knowledge of student participants. Overall, the findings of the pre- and post-intervention knowledge-based quizzes illustrate marginal knowledge improvements after using the Pharma Compound AR tool. The small improvements in quiz scores were evident in both sixth form and undergraduate students. Nevertheless, these improvements did not reach the statistical significance required to confirm that using the intervention tool would improve participants' knowledge and, thus, their quiz performance (experimental hypothesis).

Throughout the intervention period, the AR tool was used as an additional resource for participants to use alongside their conventional learning methods. Although overall quiz scores did not significantly improve, they did not fall after using the AR tool despite students performing better and worse on some question themes. The findings show no significant differences between knowledge improvement scores in the pre- and post-quizzes of sixth form or undergraduate participants. No significance was found between the mean quiz score of participants when grouped by gender, subjects (biology or chemistry), country of study, type of student, or age, indicating these factors did not impact students' learning. Sixth form participants all attended independent/private schools or colleges, so comparisons could not be made concerning the tool's effect on state-funded/public schools students' performance. Sixth form students had the largest improvement in question topics based on properties of water, formation of esters and chiral centres. Yet, they performed poorly on both pre- and post-quiz questions based on phospholipid liposome formation and the structure of fatty acids. On the other hand, undergraduate students showed the biggest improvement in questions based on fatty acid structure but also showed poor pre- and post-quiz performance on enzyme activity and zwitter ion question topics.

It cannot go without mentioning the decline in response rates from the sixth form and undergraduate participants. Participation in multi-phased research often decreases as the data collection process progresses (Salim *et al.*, 2008). However, the COVID-19 pandemic and the resulting social distancing restrictions may have contributed to an increased rate of participant dropout (discussed in greater detail in section 11.5). The dropout level was enough that the number of post-intervention participants fell below 34, the required number of participants calculated to confidently identify statistical significance according to

the sample size calculation made in the methods chapter 5.4.1. One may assume that with greater participation throughout the pre- and post-quiz elements, a significant improvement in scores may have been found. However, the opposite may become apparent, additionally greater participation may not result in the identification of significant improvements as the most academically motivated students may be more likely to participate in studies relating to education and therefore may not show much difference between their pre- and post-results. The post-intervention response rates were lower in sixth-form students, especially participants from Kenya. As mentioned, COVID-19 social distancing measures may have impacted responses and participants' proximity to the lead researcher. Participants were educated from home through the post-intervention phase of this study. Therefore, they may have missed the reminder emails due to a lack of familiarity between participants based in Kenya and the lead researcher.

7.7 Chapter Summary

The findings from the pre- and post-quiz were obtained from a varied demographic participant group. Although the quizzes were completed by undergraduate and sixth form participants of various ages, there were no public school sixth form participants or undergraduate students from other institutions or countries involved. The use of the AR Pharma Compound tool did not significantly improve the knowledge, and thus the quiz performance, of either sixth form biology and chemistry students or undergraduate pharmacy students. Post-intervention quiz scores indicate that both groups of students performed better after using the AR tool; however, the improvement did not reach statistical significance.

The results from this chapter form part of the quantitative data collected in this piece of research. Chapter 8 presents the quantitative questionnaire results. The qualitative results from the questionnaires and video call interviews will be presented and discussed later in this thesis (chapters 9 and 10) before all results are triangulated in the discussion chapter (chapter 11).

8 Year 12 and Undergraduate Student Quantitative Questionnaire Results

8.1 Introduction

In addition to quantitatively investigating changes in knowledge brought about by the use of the Pharma Compounds AR, changes in the self-reported intrinsic motivation participants possessed towards their learning caused by the use of the Pharma Compounds AR educational tool were also explored. Amended IMI pre- and post-intervention questionnaires were used to collect data contributing to meeting these objectives (Appendices 38 and 39). The questionnaires included closed and open-ended questions (results from open-ended qualitative questions are presented in Chapter 9) in addition to a series of Likert type statements and Likert scales designed to measure perceived intrinsic motivation towards learning and the usefulness of the intervention tool. The chapter begins with the response rate and demographic data of the sixth form participants (section 8.2) before the presentation of the sixth form quantitative questionnaire results (section 8.3). The response rate, demographic data (section 8.4) and quantitative questionnaire data (section 8.5) of undergraduate MPharm participants' follow after the presentation of sixth form data. The results of both groups are discussed in section 8.6.

8.2 Year 12 Questionnaire Response Rates and Demographic Results

A total of 64 Year 12 biology and chemistry students consented to participate in the completion of the pre- and post-intervention questionnaire. 63 consenting participants completed the pre-questionnaire, with 24 students continuing to complete the post-questionnaire after the intervention period. The response rate and demographic data have been tabulated in table 8.1 below.

		Consented	Pre-Questionnaire	Post-Questionnaire
Total Number of Students (RR%)		64	63 (98.4%)	24(37.5%)
Gender	Male	15	15 (23.8%)	5 (20.8%)
	Female	45	45 (71.4%)	17 (70.8%)
	Prefer not to say	4	3 (4.8%)	2 (8.3%)
Country	UK	17	17 (27%)	15 (62.5%)
	Kenya	47	46 (73.0%)	9 (37.5%)
Age	16-17 years	56	55 (87.3%)	21 (87.5%)
	18-19 years	8	8 (12.7%)	3 (12.5%)
	19+ years	0	0 (0%)	0 (0%)
	Prefer not to say	0	0 (0%)	0 (0%)
Type of School	Independent	64	63 (100%)	24 (100%)
Subject	Biology	13	13 (20.6%)	3 (12.5%)
	Chemistry	10	10 (15.9%)	4 (16.7%)
	Biology and Chemistry	41	40 (63.5%)	17 (70.8%)

Table 8.1 displays the response rates for Year 12 Biology and Chemistry students' pre- and post-questionnaires.

Table 8.1 shows that the response rates of participants who completed the questionnaires fell from 98.4% (pre-intervention) to 37.5% (post-intervention) concerning the number of participants who initially consented. The proportions of male and female students remained almost identical across the two questionnaires, as did the proportions of participants from each age group. The proportion of students who attend schools in Kenya fell from 73% in the pre-questionnaire to 37.5% in the post-questionnaire, whereas the percentages of UK students rose from 27% to 62.5% (pre- to post-, respectively). All responses for both the pre- and post-questionnaires were from participants who attended independent schools. Of the participants that completed the pre-intervention questionnaire, 63.5% were enrolled on simultaneous biology and chemistry courses, 20.6% enrolled on biology-only courses, and the remaining 15.9% enrolled on chemistry-only courses. However, the distribution of students in the post-intervention questionnaire is as follows; 70.8% of students were enrolled on both biology and chemistry courses, 12.5% enrolled on biology courses, and 16.7% enrolled on chemistry courses. Between the pre- and post-questionnaire participants, the proportions of students who had previously been involved in research before this

project was almost identical – 46% and 47.1% in the pre- and post-questionnaires, respectively.

8.3 Year 12 Questionnaire Results

8.3.1 Internal consistency

As explained in Methods Chapter 5.8.1, Cronbach alpha (α) was used to measure the internal consistency of not only the motivation (interest/enjoyment) and usefulness (value) adapted IMI Likert scales on pre- and post-questionnaires but also the series of pre-questionnaire motivation Likert type statements, regarding motivation in different learning sessions. A Cronbach α score of 0.7 was obtained for the pre-questionnaire scale regarding motivation towards learning in different learning environments. The pre- and post-questionnaire adapted IMI scales generated overall Cronbach α scores of 0.87 and 0.91, respectively. These values indicate a good reliability level within the scales of both questionnaires (scores above 0.7 are considered acceptably reliable) (Chapter 4.6.1). The Cronbach α scores of the individual motivation and usefulness subscales in both the pre- and post-questionnaires are also listed in table 8.2. Regarding the IMI usefulness scale in the pre-questionnaire, a lower Cronbach score would be expected as it consisted of only three items (4.6.1). However, it did not negatively impact the overall IMI scale score.

	Pre-questionnaire Cronbach alpha score (a)	Post-questionnaire Cronbach alpha score (a)
Motivation in different learning sessions	0.70	n/a
IMI Motivation	0.85	0.88
IMI Usefulness	0.65	0.92
Overall IMI (motivation and usefulness)	0.87	0.91

Table 8.2 displays Cronbach alpha scores of the various scales included in the pre- and post-intervention questionnaires of sixth form students.

8.3.2 Descriptive and Inferential Statistics

As discussed in the methods chapter (Chapter 5.8.1), the median was determined to be the most appropriate analytical method to measure the central tendency of individual Likert statements. Table 8.3 details the median scores of eight Likert style questions and statements from the pre-intervention questionnaire (non-IMI questions). These statements recorded students' perspectives on the use of technology in education and their self-reported motivation while teaching sessions of different styles.

The median response from participants, when asked whether they agree with the use of mobile devices in their teaching sessions, was 4 (agree). When asked how important the use of technology is in education, participants gave a median response of 4 (agree). Each of the six Likert type statements that revolved around self-reported motivation in different styled teaching sessions generated a median score of 4 (agree) except when the teaching session was of a 'lecture' format – the median score for this statement was 3 (neither).

Question/Statement	Pre-questionnaire Median Score
Do you agree with the use of mobile devices (tablets, smartphones etc.) in teaching sessions?	4
How important to you is the use of technology in education?	4
How would you rate your motivation towards learning while using computer-generated simulations?	4
How would you rate your motivation towards learning while in demonstration?	4
How would you rate your motivation towards learning while in laboratory sessions?	4
How would you rate your motivation towards learning while in lectures?	3
How would you rate your motivation towards learning while in workshops?	4
How would you rate your motivation towards learning when revising using your current methods?	4

Table 8.3 displays the median scores from the pre-questionnaire Likert type statements of students' self-reported motivation in each type of teaching session.

The post-questionnaire Likert type statement data is presented below in table 8.4. The median score of 4 (easy) was calculated when participants were asked how difficult or easy they found the AR educational tool to use. The median frequency of use was reported to be 'less than twice a week' (1). The median rating given by participants when asked to rate their ability to visualise similar learning material after using the AR Pharma Compounds educational tool was 4 (easy).

Question/Statement	Post-questionnaire Median Score
How difficult/easy did you find the Pharma Compounds learning tool to use?	4
On average, how many times a week did you use the Pharma Compounds learning tool?	1
How would you rate your ability to visualise similar learning material after using the AR Pharma Compounds learning tool?	4

Table 8.4 displays the median scores for the post-questionnaire non-IMI Likert style questions.

The individual median scores of the IMI Likert statements from the pre- and post-intervention questionnaires are listed below in table 8.5 (Appendices 36 and 37) (IMI Likert statements are listed in section 8.3.3.5). A score of 1=not true at all, 4=somewhat true, and 7=very true. IMI statements 1, 4, 7, 8, 9 and 10 show an increase in participants' agreement

after the use of the AR intervention tool. Statements 2, 3 and 6 did not show any changes in participant agreement; statement 5 was the only item to show a decrease in its median value.

IMI statement	Pre-Questionnaire Median Score	Post-Questionnaire Median Score	Wilcoxon Signed-Rank test p-value
1	4	5	0.683
2	4	4	0.118
3	5	5	0.092
4	4	5	0.001*
5	6	5	0.209
6 (R)	6	6	0.166
7	4	5	0.012*
8 (R)	4	6	0.000*
9	4	5.5	0.062
10	4	5	0.012*
11	-	6	-
12	-	5	-
13	-	6	-
14	-	5.50	-

Table 8.5 displays both the pre- and post-intervention individual median and mean scores of the IMI statements for Year 12 students. *Statistical significance was reached when p<0.05

Of the 10 IMI Likert statements that were on both the pre- and post-intervention questionnaire, a significant difference was found in statements 4, 7, 8 and 10 ($p<0.05$). The remaining statements showed no significant differences between the pre- and post-intervention Likert responses ($p>0.05$).

The analysis of the adapted IMI questions was carried out per the requirements of the inventory. First, statements branded with '(R)' had their scores reversed (recorded scores were to be subtracted from 8). These statements were negatively phrased and required the scores to be inverted before analysis could be carried out, such that the score matched the positive phasing of the remaining statements. Each IMI statement was then grouped into the respective subscale in accordance with the intrinsic motivation inventory, and the average agreement score was calculated as discussed in chapter 5.8.1 (McAuley *et al.*, 1989)

– interest/enjoyment, which is considered to be a measure of intrinsic motivation, and value/usefulness. These results are tabulated in table 8.6 and show on average, participants responded with a higher agreement to the IMI post-questionnaires Likert statements.

	Mean Pre-Questionnaire Score	**Mean Post-questionnaire Score**
Interest/Enjoyment (Motivation)	4.27	5.18
Usefulness/Value	5.06	5.25

Table 8.6 displays the mean motivation and usefulness scores for both pre- and post-intervention questionnaires (means for all submitted pre- and post-intervention questionnaires).

Dependent t-test analysis of the IMI subscales found that there was a significant difference between the pre- and post-intervention interest/enjoyment subscale ($t_{(23)}$ = -3.056, p<0.05) and thus, the null hypothesis was rejected – there was no significant difference in self-reported motivation towards learning after using the AR Pharma Compounds tool as mentioned in the methods chapter (section 5.7.1). Therefore, the use of the AR Pharma Compounds tool contributed to users' increased motivation towards learning. The usefulness/value subscale showed no significant differences between the means of the pre- and post-intervention questionnaires ($t_{(23)}$ = -0.685, p>0.05).

8.3.3 Percentage distribution of Likert Type and Likert Scale scores

In addition to descriptive and inferential statistics, the percentage distribution of each Likert-type and Likert scale statements found in the sixth form participants' pre- and post-questionnaires was analysed. Figures 8.1 to 8.8 display the distribution of responses to the pre-questionnaire non-IMI Likert statements followed by the post-questionnaire non-IMI Likert statements in figures 8.9 to 8.11. Finally, figures 8.12 to 8.25 display the side-by-side

percentage distribution of responses to each IMI Likert statement in the pre- and post-questionnaires.

8.3.3.1 Pre-Questionnaire Non-IMI Likert Percentage Distribution

Below are the percentage distributions of responses to the sixth form participant pre-questionnaire non-IMI Likert statements.

Question 1 - Do you agree with the use of mobile devices (tablets, smartphones etc.) in teaching sessions?

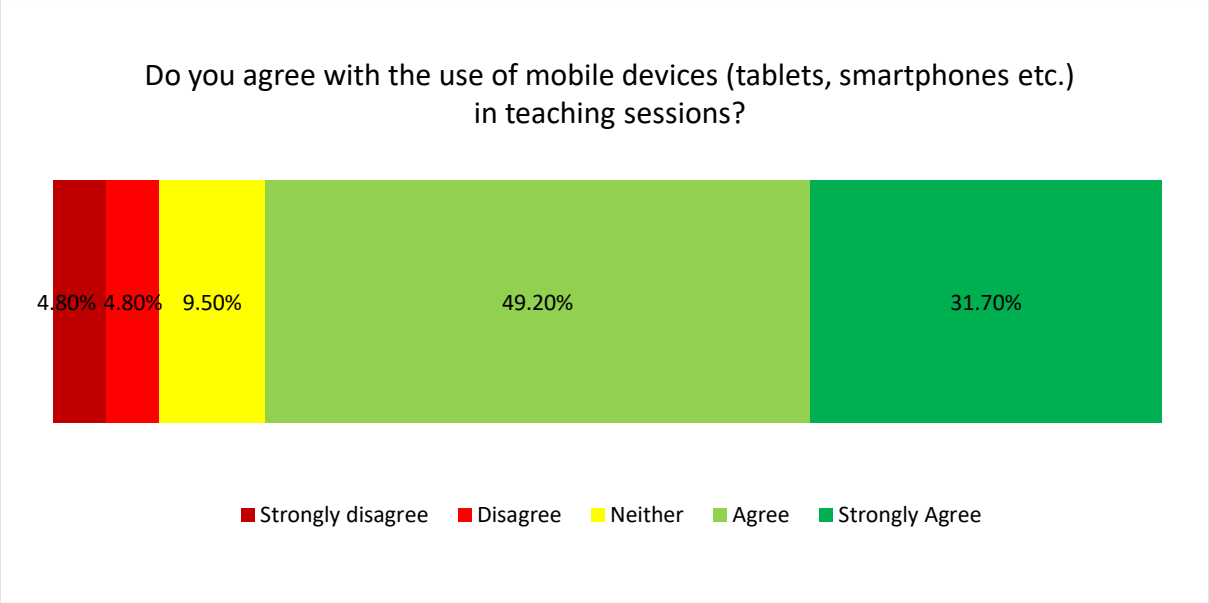


Figure 8.1 shows that the greatest proportion of sixth form students 'agreed' or 'strongly agreed' with the use of mobile devices, such as smartphones and tablets, in their teaching sessions (80.9%). Conversely, a very small percentage either 'disagreed' or 'strongly disagreed' with the use of mobile devices (9.6%).

Question 2 - How important to you is the use of technology in education?

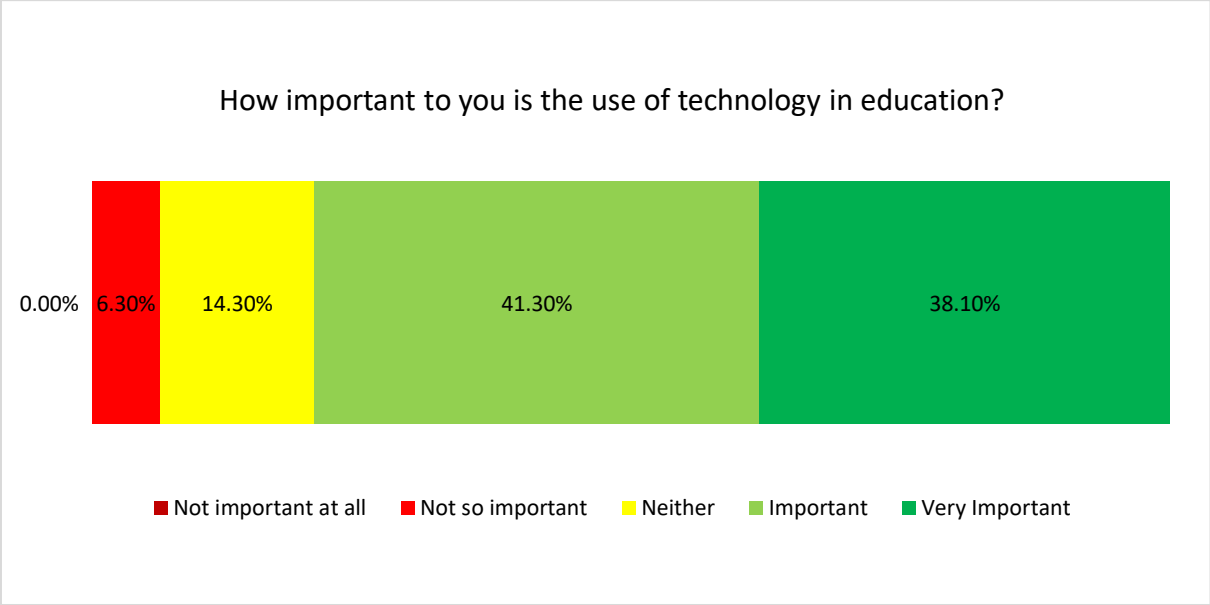


Figure 8.2 illustrates that most year 12 participants believe using technology is either 'important' or 'very important' (79.4%). No student believed technology had 'no importance at all' in education; however, 6.3% believed it was 'not so important'.

Question 3 - How would you rate your motivation towards learning while using computer-generated simulations?

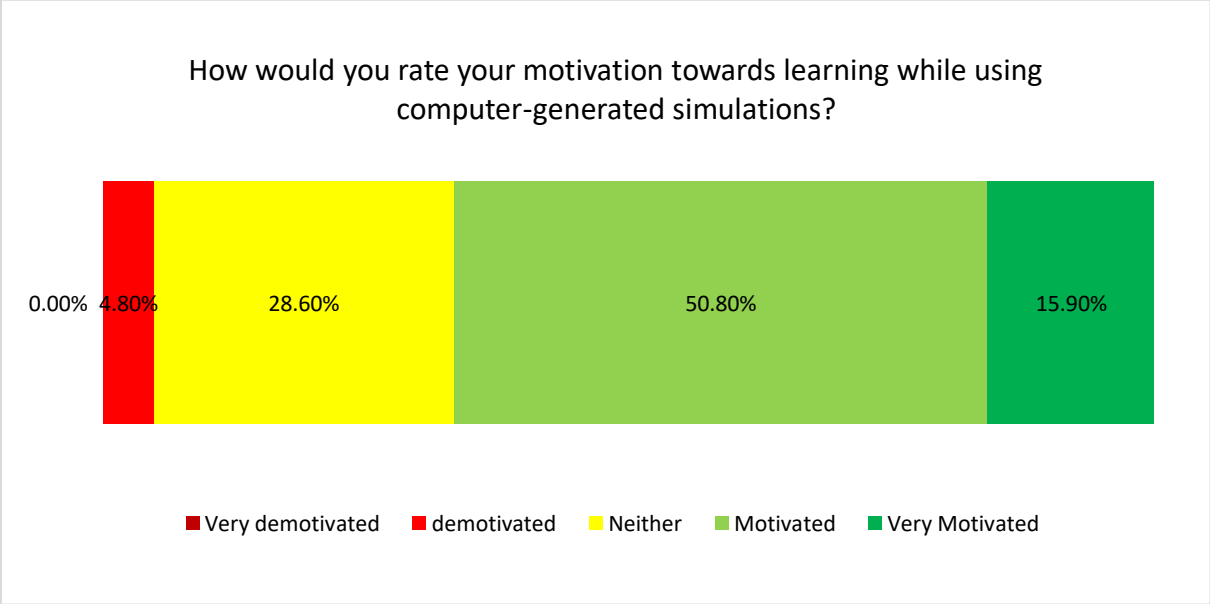


Figure 8.3 shows that 66.7% of students reported that they feel 'motivated' or 'very motivated' to learn when computer-generated simulations are involved. 28.6% of students feel 'neither' motivated nor demotivated to learn, while 4.8% feel demotivated by using computer-generated simulations.

Question 4 - How would you rate your motivation towards learning while in demonstrations?

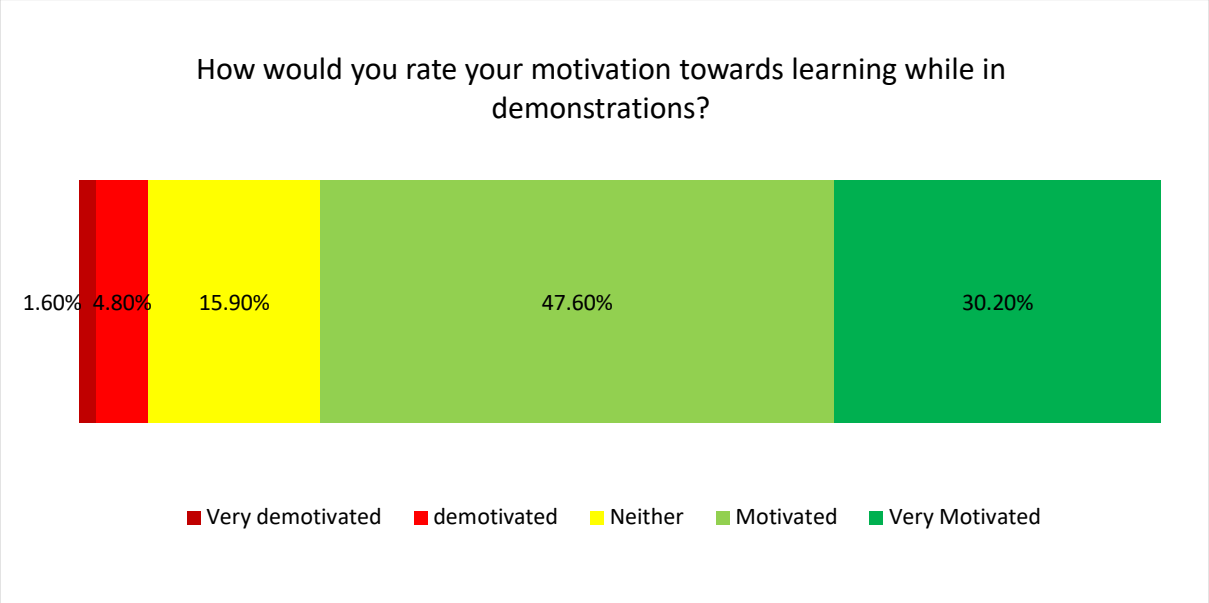


Figure 8.4 shows that the majority of students are either 'motivated' or 'very motivated' when demonstrations are utilised in teaching sessions (77.8%), whereas 6.4% of year 12 students reported they feel either 'demotivated' or 'very demotivated' when demonstrations are used in teaching sessions.

Question 5 - How would you rate your motivation towards learning while in laboratory sessions?

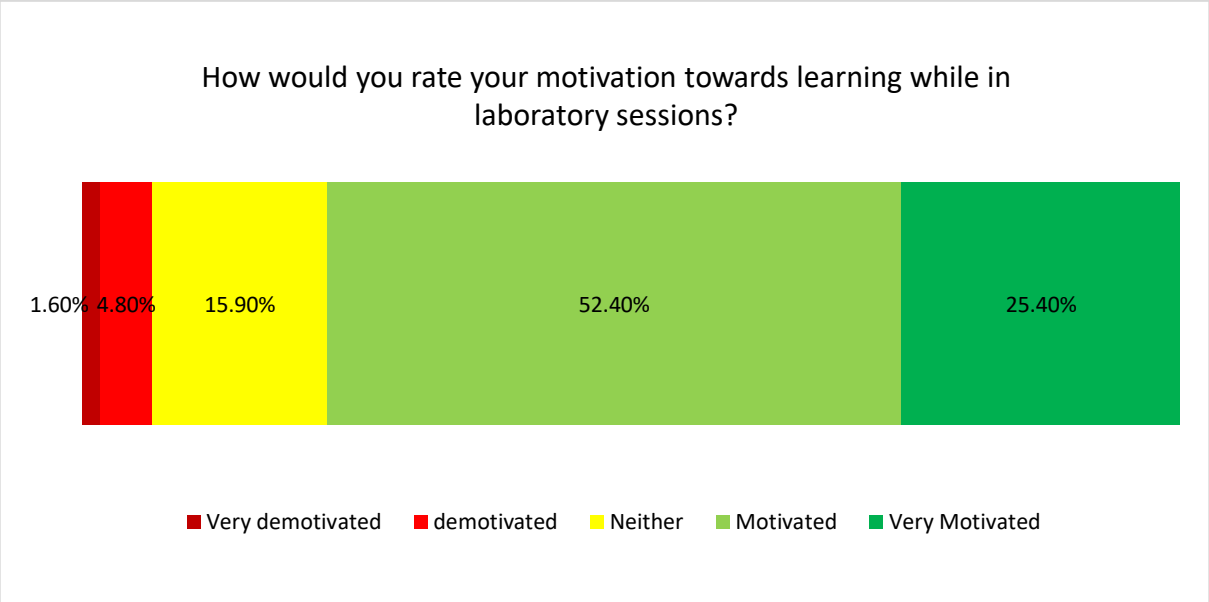


Figure 8.5 illustrates that just over 50% of year 12 chemistry and biology students reported being 'motivated' when in laboratory sessions. A further 25.4% of participants stated to be 'very motivated' by laboratory sessions. Only 6.4% of students reported feeling either 'very demotivated' or 'demotivated' in laboratory sessions.

Question 6 - How would you rate your motivation towards learning while in lectures?

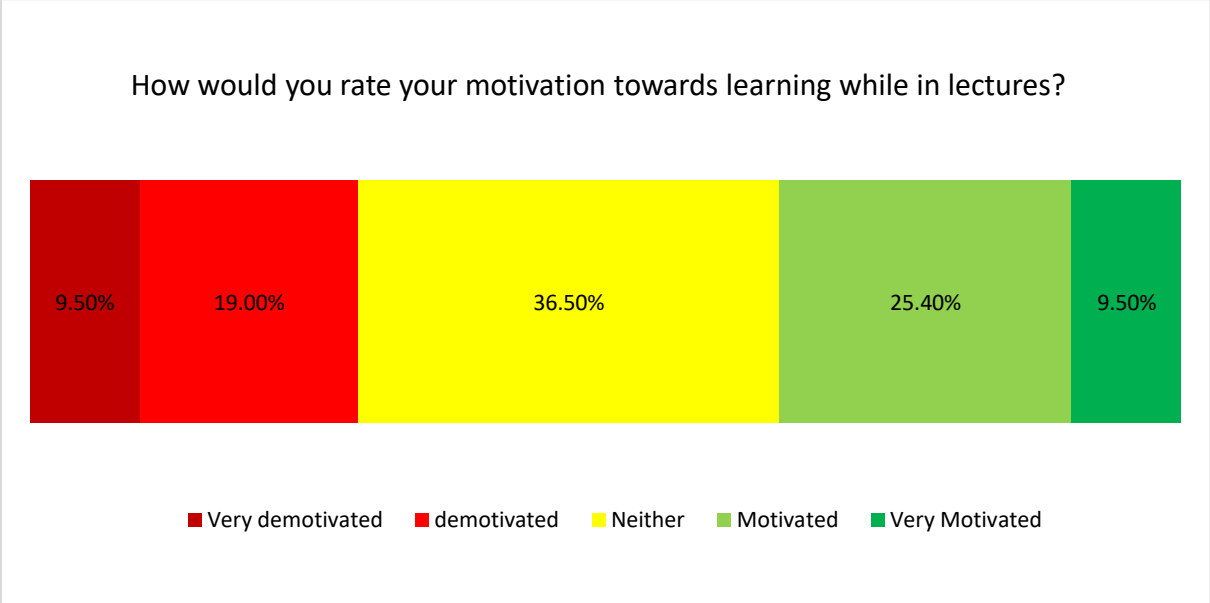


Figure 8.6 illustrates that the largest portion of students were undecided (neither) about whether or not they felt motivated to learn in lecture teaching sessions. 34.9% of participants were either 'motivated' or 'very motivated to learn when in lectures, whereas 28.5% of students were either 'very demotivated' or 'demotivated'.

Question 7 - How would you rate your motivation towards learning while in workshops?

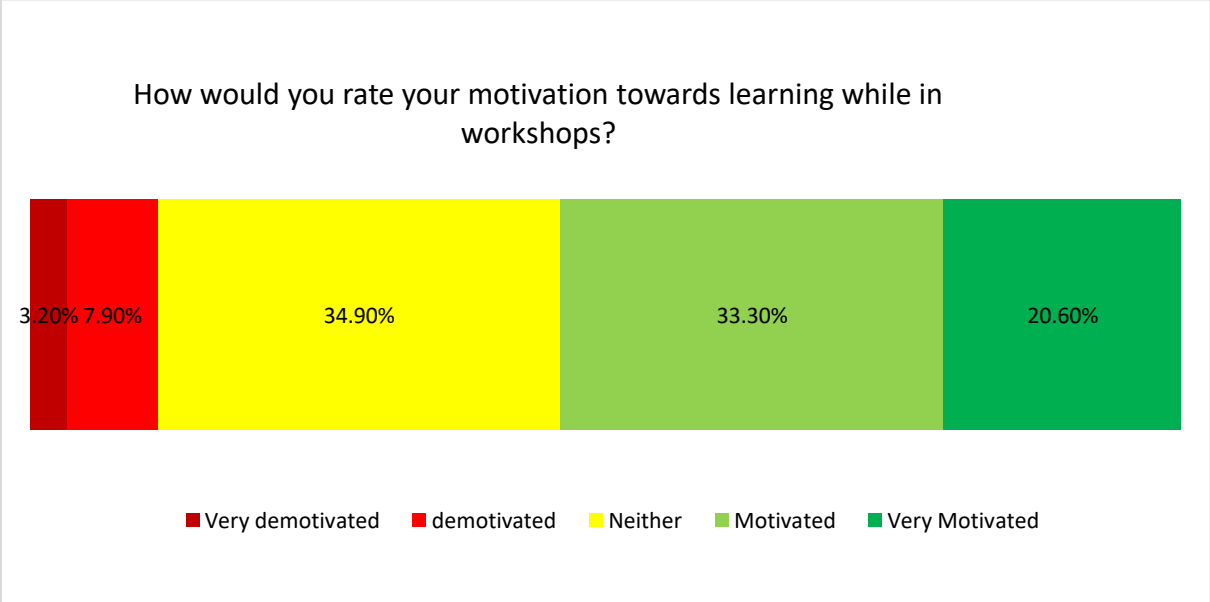


Figure 8.7 shows that almost 35% of year 12 chemistry and biology students selected 'neither' when asked to rank their motivation while in workshops. Over 50% of participants reported being either 'motivated' or 'very motivated' by workshop teaching sessions. Conversely, just over 10% of students reported being either 'very demotivated' or 'demotivated' in these teaching sessions.

Question 8 - How would you rate your motivation towards learning when revising using your current methods?

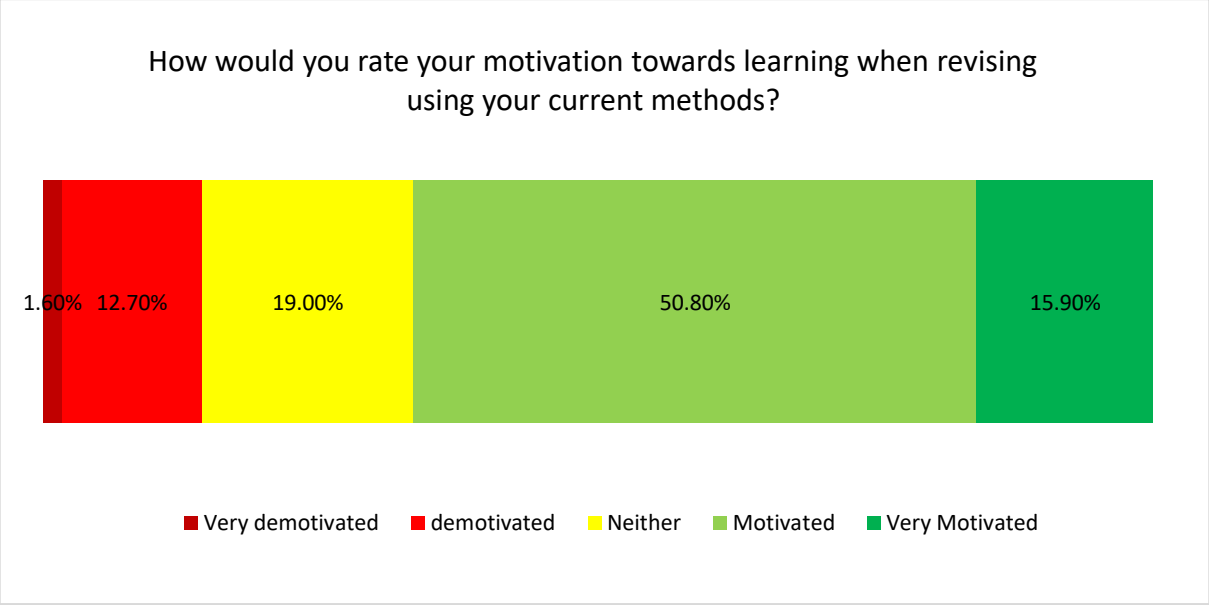


Figure 8.8 shows that just over 50% of year 12 participants reported feeling 'motivated' when revising using their well-established methods. A further 15.9% reported that they feel 'very motivated'. On the other hand, 12.7% reported feeling 'demotivated', with 1.6% highlighting that they feel 'very demotivated'.

The results of the sixth form pre-questionnaire Likert-statements above illustrate that the majority of students were in favour of using mobile technology during their teaching sessions (statement 1) and believe that it has importance in their learning (statement 2). More than 50% of sixth form participants reported they were either motivated or very motivated when in teaching sessions that utilise computer generated simulations (statement 3), demonstrations (statement 4), laboratory sessions (statement 5), workshops (statement 7) and revision sessions (statement 8). With respect to lectures, the responses were varied, a similar number of participants reported their motivation as either demotivated or motivated.

8.3.3.2 Post-Questionnaire Non-IMI Likert Percentage Distribution

Below are the percentage distributions of responses to the sixth form participant post-questionnaire non-IMI Likert statements.

Question 1 - How difficult/easy did you find the Pharma Compounds learning tool to use?

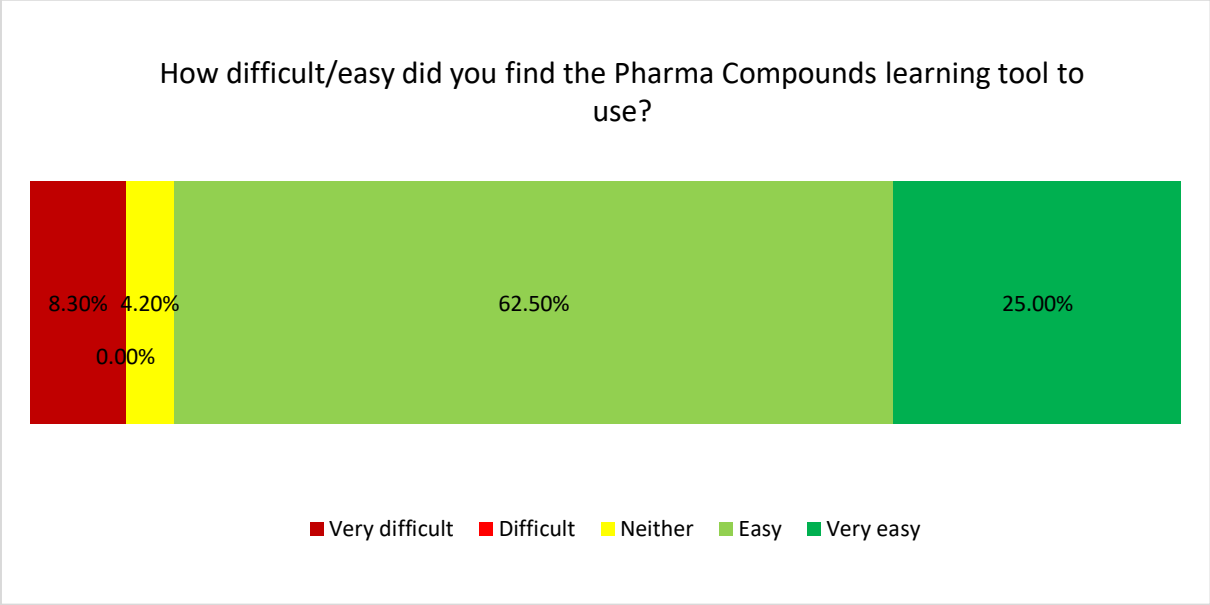


Figure 8.9 illustrates that a large portion of participants found the Pharma Compounds app either 'easy' or 'very easy' to use (85%). Conversely, a very small percentage had difficulty with the AR learning tool (8.3% selected 'very difficult').

Question 2 - On average, how many times a week did you use the Pharma Compounds learning tool?

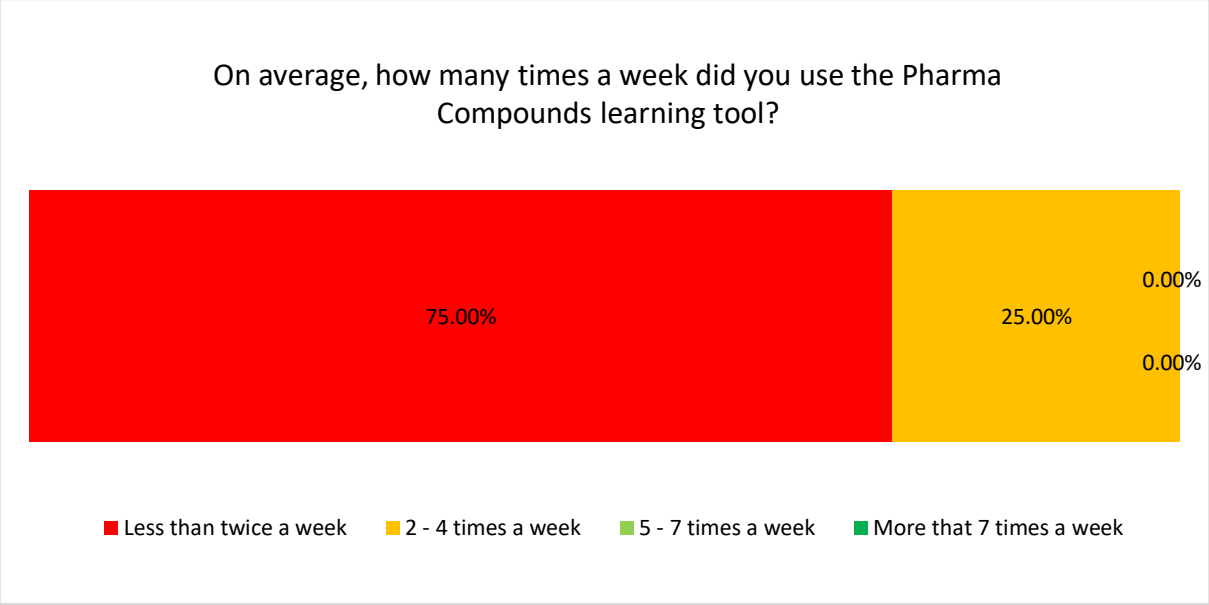


Figure 8.10 shows that the AR learning tool was reportedly used either 'less than twice a week' or between '2 – 4 times a week'. Three-quarters of participants had reported using the Pharma Compounds app less than twice a week within the intervention period. The remaining third reported using the tool 2 – 4 times a week.

Question 3 - How would you rate your ability to visualise similar learning material after using the AR Pharma Compounds learning tool?

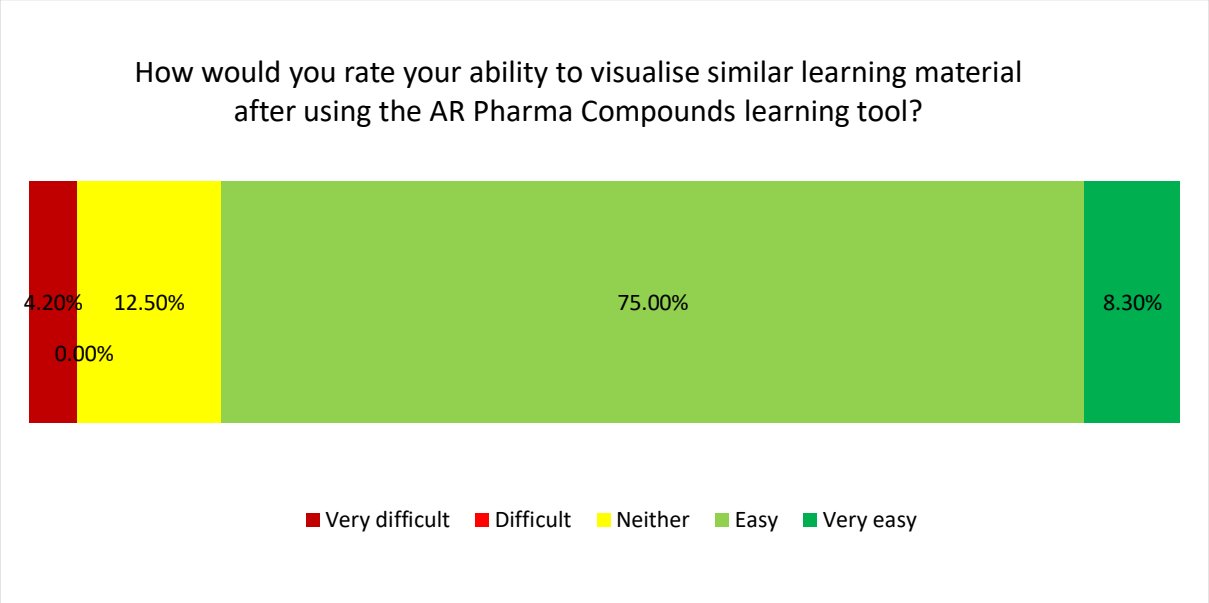


Figure 8.11 shows that after the intervention period, most participants reported being able to visualise learning material 'easily' or 'very easily'. Only 4.2% of the participants reported difficulty visualising learning material; all of them reported it as being 'very difficult.

The vast majority of sixth form students who completed the post-intervention

questionnaire reported that the Pharma Compounds AR tool was either easy or very easy to

use in their studies (statement 1). Nevertheless, all participants used the AR educational tool no more than 2 to 4 times weekly, the majority reported to have only used the tool less than twice a week (statement 2). After the incorporating the Pharma Compounds AR tool into their learning practices, over two thirds of sixth form participants reported visualising similar learning material either easy or very easy (statement 3).

8.3.3.3 Pre- and Post-Questionnaire IMI Scales Percentage Distribution

Below are the percentage distributions of responses to each statement from the IMI scales used in the pre- or post-questionnaires. Pre- and post-questionnaire IMI statements 1 to 10 are presented side-by-side for direct comparison. Statements 11 to 14 were only present in the post-questionnaire and focused on the usefulness of the intervention tool.

Generally, students demonstrated a higher degree of agreement to statements that focus on enjoyment, and thus motivation, when the statement referred to the Pharma Compound AR educational tool rather than conventional methods of learning. A similar trend was evident in the Likert statements related to the intervention tool's usefulness.

Likert scale anchor points

Not true at all			**Somewhat true**			**Very true**
1	2	3	4	5	6	7

Statement 1: I enjoy my current learning/revision methods very much - I enjoyed using the Pharma Compounds learning tool very much

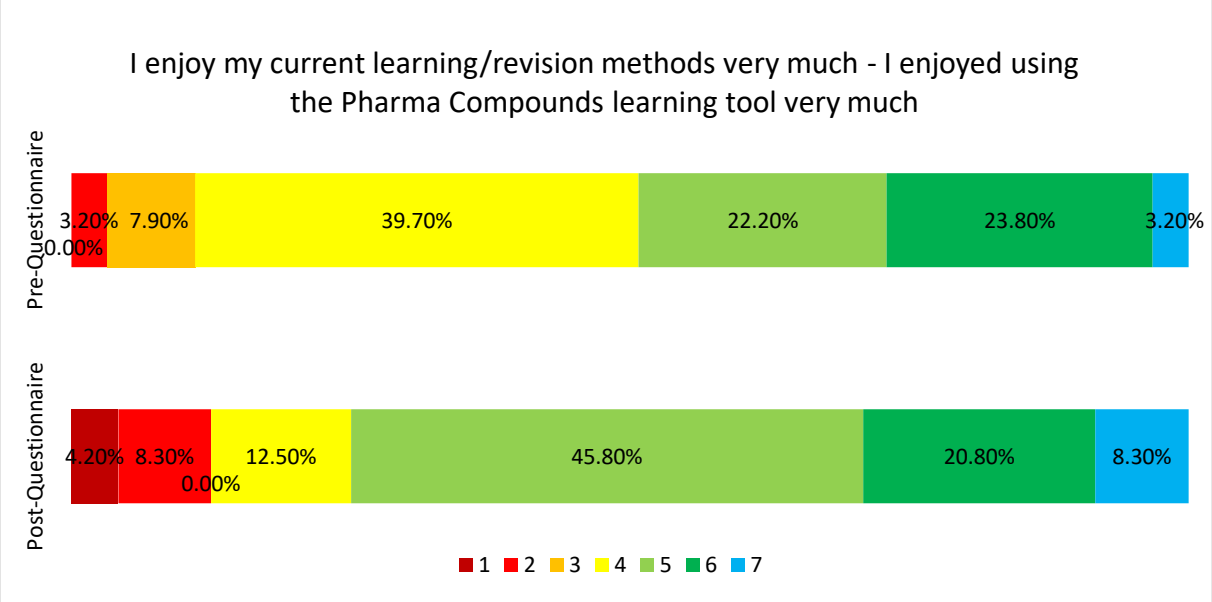


Figure 8.12 illustrates that just under 50% of pre-questionnaire participants enjoyed their learning/revision methods before the introduction of the AR learning tool to varying degrees (5, 6 and 7). The diagram also shows that most post-questionnaire participants enjoyed using the AR learning tool. 74.9% of post-questionnaire participants rated their agreement to this Likert scale item as a 5, 6 and 7 (45.8%, 20.8% and 8.3%).

Statement 2: While I learn/revise using my current methods, I think about how much I enjoyed it - While using the Pharma Compounds learning tool, I was thinking about how much I enjoyed it

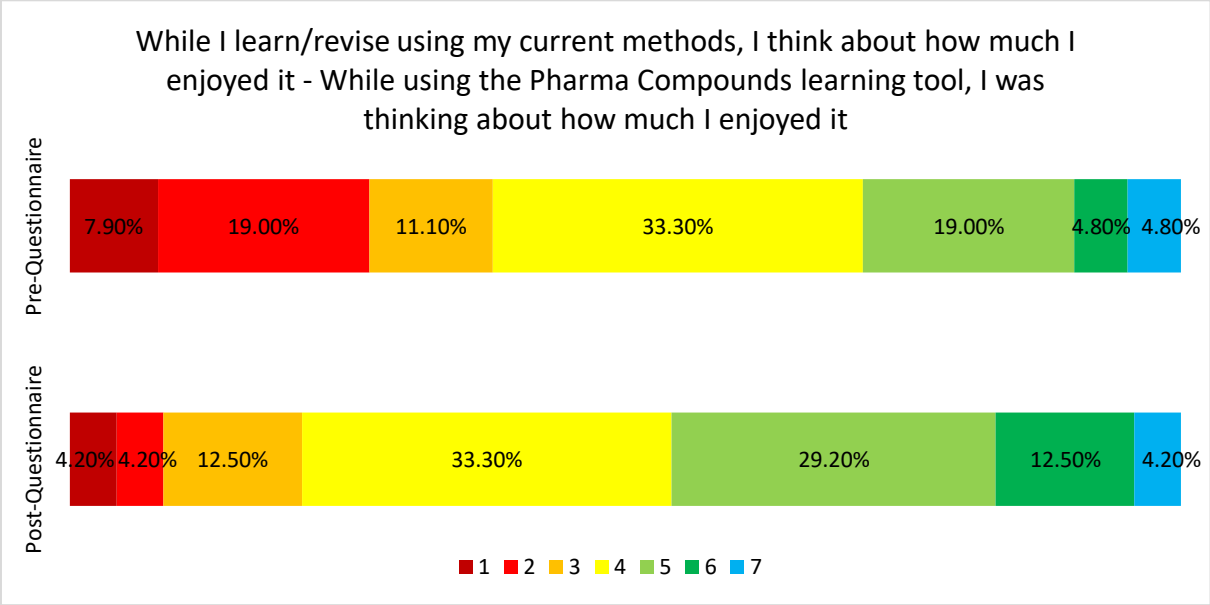


Figure 8.13 shows that the largest proportions of the agreement for this Likert statement in both pre- and post-questionnaires were 'somewhat true' (4). A large proportion of responses in the post-questionnaire towards the 'very true' end of the scale – 29.2% for anchor point 5, 12.5% for point 6 and 4.2 % for point 7. The distribution of responses for the pre-questionnaire were more evenly skewed.

Statement 3: I think using my current learning/revision methods could help me to improve my academic performance - I think using the Pharma Compounds learning tool could help me to improve my academic performance

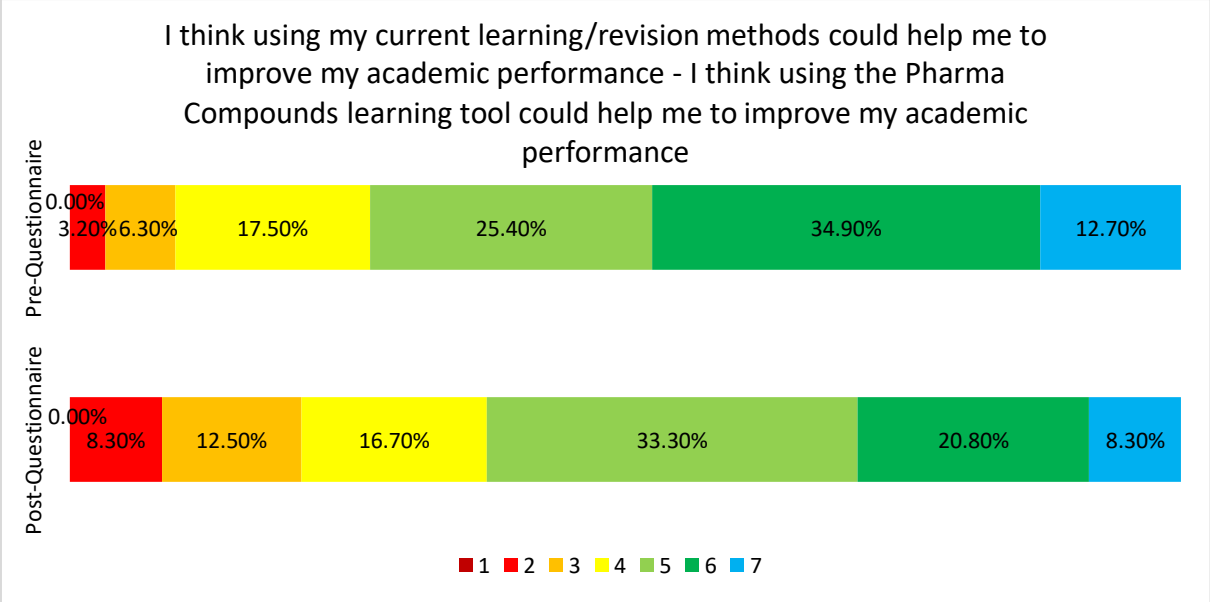


Figure 8.14 shows that the agreement for this Likert statement in pre- and post-intervention questionnaires followed the same trend. Over 50% of participants in both questionnaires responded with degrees of agreement with the statement (5, 6 or 7). A larger proportion of participants scored the scale either 5, 6 or 7 on the pre-intervention questionnaire compared to the post-questionnaire (73% compared to 62.4, respectively).

Statement 4: I would describe my current learning/revision methods as very interesting - I would describe the Pharma Compounds learning tool as very interesting

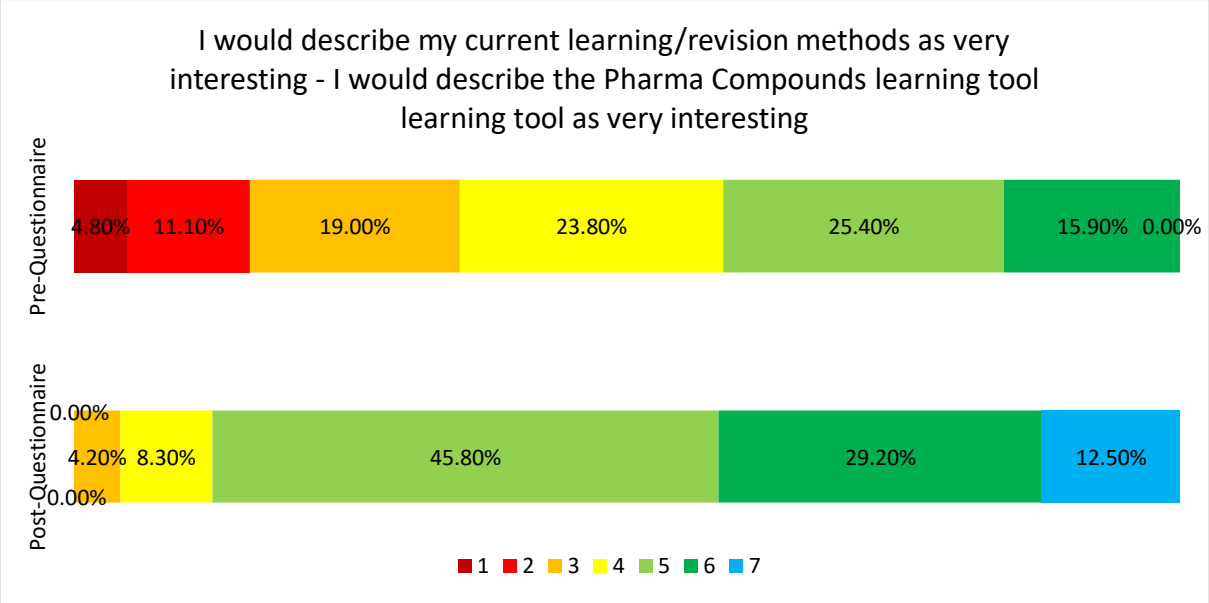


Figure 8.15 illustrates a large difference between the pre- and post-intervention agreement with this Likert statement. A significantly larger proportion of students agreed with this statement when completing the post-questionnaire compared to the pre-questionnaire - 87.5% of participants scored their agreement as 5, 6 or 7. In contrast, the same level of agreement was only shared by 41.3% of participants from the pre-questionnaire (0.0% of participants registered anchor point 7 in the pre-questionnaire). In addition, no participants from the post-intervention questionnaire scored their agreement as either 1 or 2 (not true at all), whereas 15.9% of pre-questionnaire participants scored their agreement as 1 or 2.

Statement 5: I believe my current learning/revision methods are of some value to me - I believe the Pharma Compounds learning tool learning tool could be of some value to me

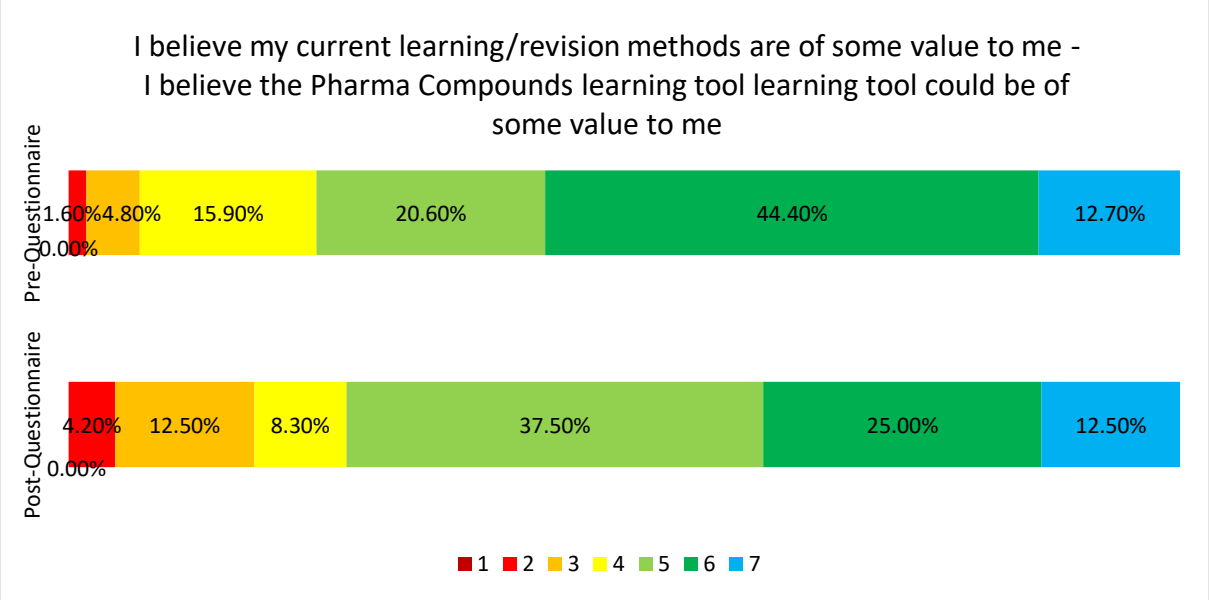


Figure 8.16 shows that the responses for these Likert statements in both the pre- and post-intervention questionnaires are quite similar – a similar proportion of students scored their agreements as either 5, 6 or 7 (77.7% and 75%, respectively). In addition, both pre- and post-Likert statements had zero participants record anchor point 1 as their level of agreement, however, points 2 and 3 had more engagement in the post-questionnaire when compared to the pre-questionnaire (4.2% compared to 1.6% and 12.5% compared to 4.8%).

Statement 6: My current learning/revision methods do not hold my attention at all (R) - The Pharma Compounds learning tool did not hold my attention at all (R)

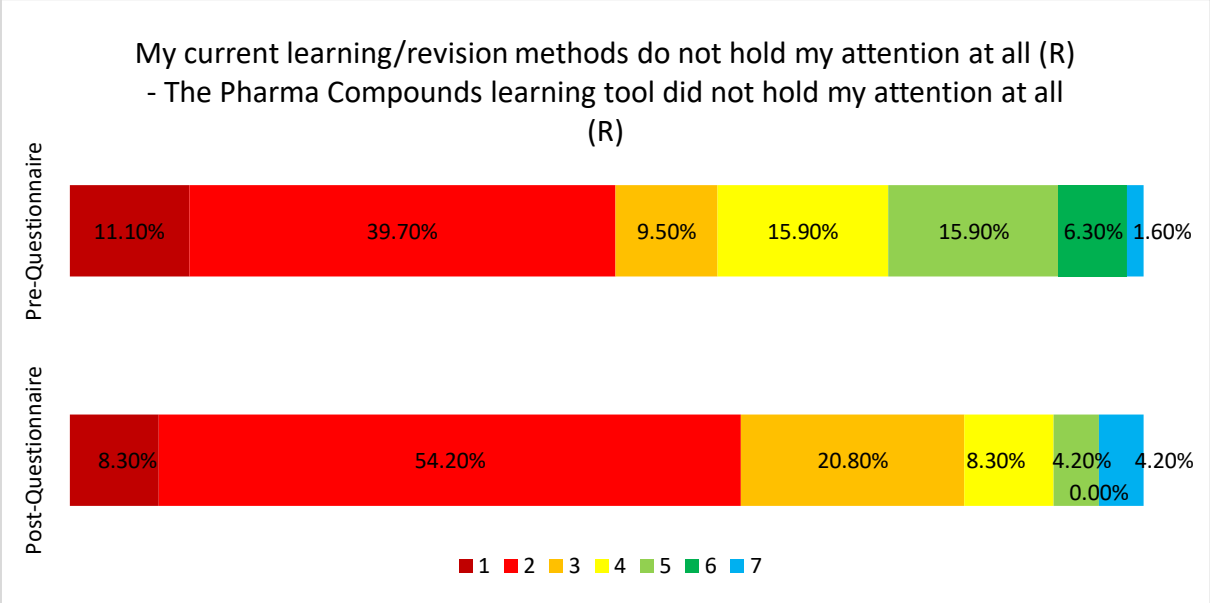


Figure 8.17 shows that both the pre- and post-Likert statement responses followed similar trends. Both statements show that the majority of students did not agree with the statement. The largest proportion of participants who completed the pre-questionnaire selected anchor point 2 (39.7%), followed by anchor points 4 and 5 (15.9). The largest proportion in the post-questionnaire was anchor point 2 (54.2%). The next largest proportion was anchor point 3 (20.8%).

Statement 7: My current learning/revision methods are fun to use - The Pharma Compounds learning tool was fun to use

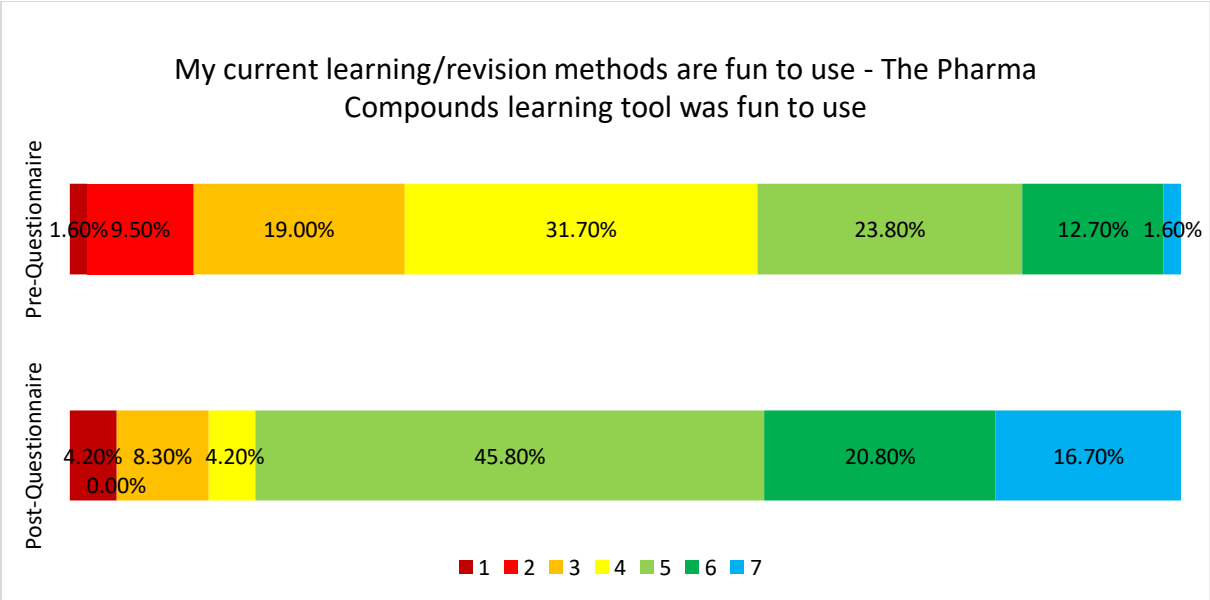


Figure 8.18 illustrates that a much greater proportion of participants agreed with this Likert statement when completing the post-intervention questionnaire - 83.3% of participants scored their agreement as 5, 6 and 7, whereas that proportion is just 38.1% with respect to anchor points 5, 6 and 7. Anchor point 4, 'somewhat true' (31.7%), had the larger proportion of participants in the pre-questionnaire, whereas the largest proportion for the post-questionnaire was seen at anchor point 4 (45.8%).

Statement 8: I think my current learning/revision methods are boring (R) - I thought the Pharma Compounds learning tool was boring (R)

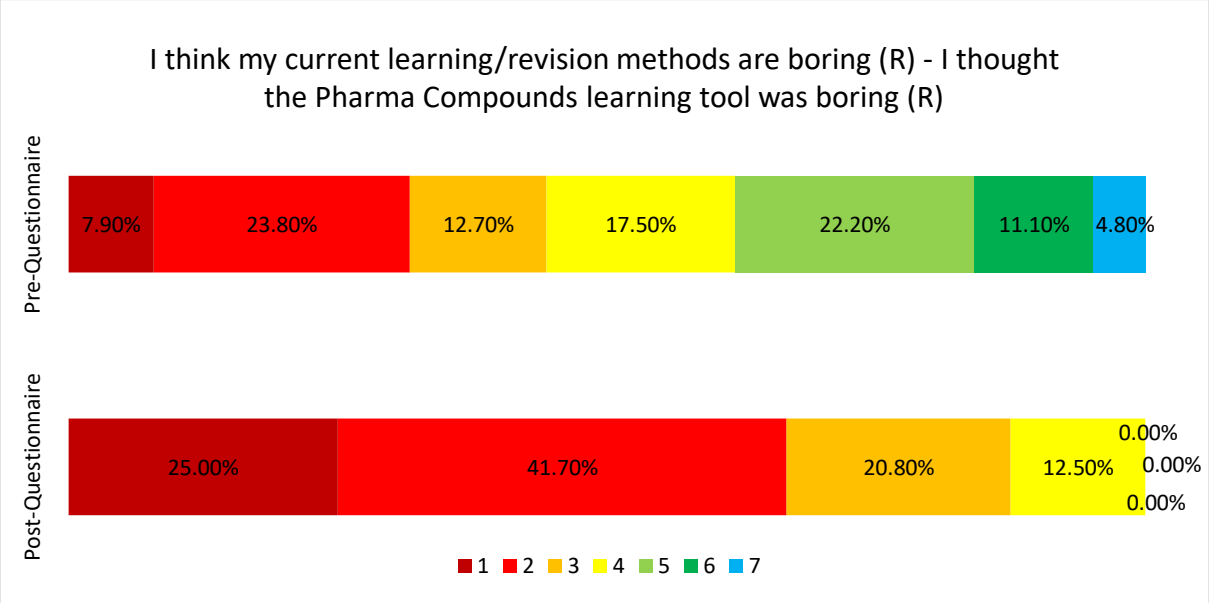


Figure 8.19 illustrates quite a noticeable difference between pre- and post-intervention participant responses. The agreement with this Likert statement in the pre-questionnaire shows a relatively even distribution from anchor points 1 to 7. The largest proportion was seen as anchor point 2, closely followed by anchor point 5 (23.8%). However, the distribution of anchor responses for the post-questionnaire Likert statement is heavily skewed to one side. All responses ranged from anchor point 1 to anchor point 4 – the largest being anchor point 2, followed by anchor point 1 (41.7% and 25%, respectively).

Statement 9: I think that it is important to use my current learning/revision methods because it can develop visualisation skills - I think that it is important to use the Pharma Compounds learning tool because it can develop my visualisation skills

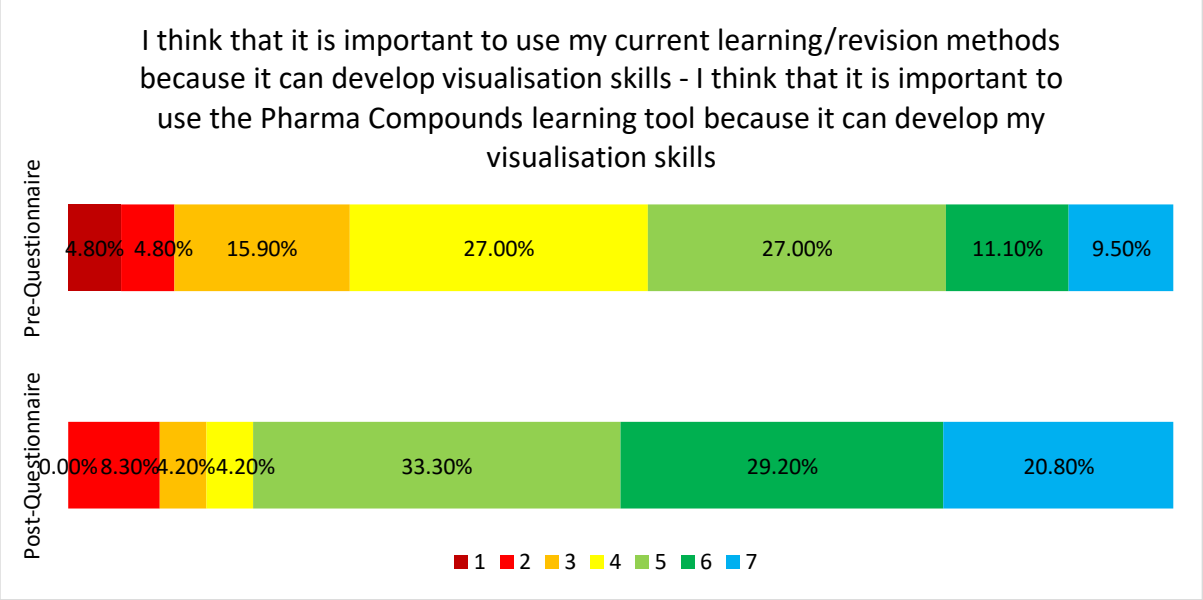


Figure 8.20 shows that the pre- and post-agreement responses to this Likert statement follow similar trends. The post-questionnaire responses had a noticeably larger proportion of participants who chose to select anchor points 5, 6 and 7 (83%). Additionally, there were no recorded responses to anchor point 1. The distribution of responses for the pre-intervention questionnaire was more evenly distributed among the 7 anchor points. The largest proportions were found to be at anchor points 4 and 5.

Statement 10: I think my current learning/revision methods are quite enjoyable - I thought the Pharma Compounds learning tool was quite enjoyable

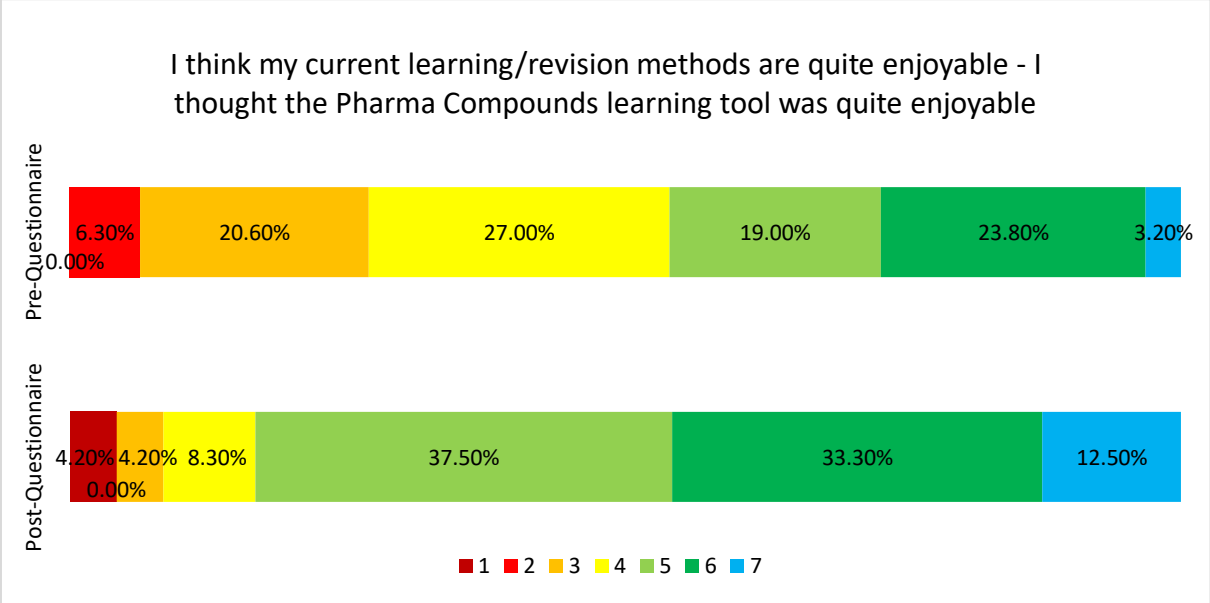


Figure 8.21 shows that again the agreements of the pre- and post-Likert statements follow similar trends leaning towards 'very true'. No participant selected anchor point 1 in the pre-questionnaire, whereas no student selected anchor point 2 in the post-questionnaire. The largest proportion seen in the pre-questionnaire is anchor point 4 (27%), closely followed by points 6 and 3 (23.8% and 20.6%). The post-questionnaire displayed that the largest proportion of participants selected anchor point 5 (37.5%), points 6 and 7 followed and the next largest proportions (33.3% and 12.5%).

Statement 11: I think the Pharma Compounds learning tool is useful for visualising difficult material

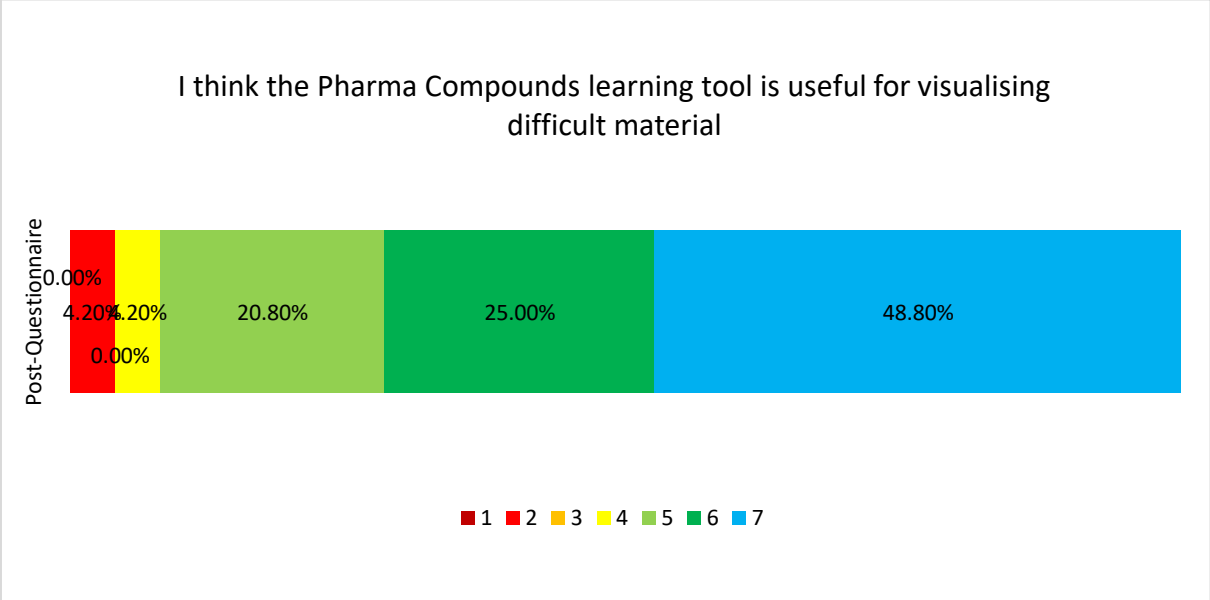


Figure 8.22 illustrates that a significant number of participants from the post-questionnaire agreed with this Likert statement. Just under 50% of students selected their agreement as 'very true' (anchor point 7), with an additional 25% selecting anchor point 6. The only anchor point selected by participants below point was anchor point 2 (4.2%).

Statement 12: I think the Pharma Compounds learning tool is an important revision/learning tool

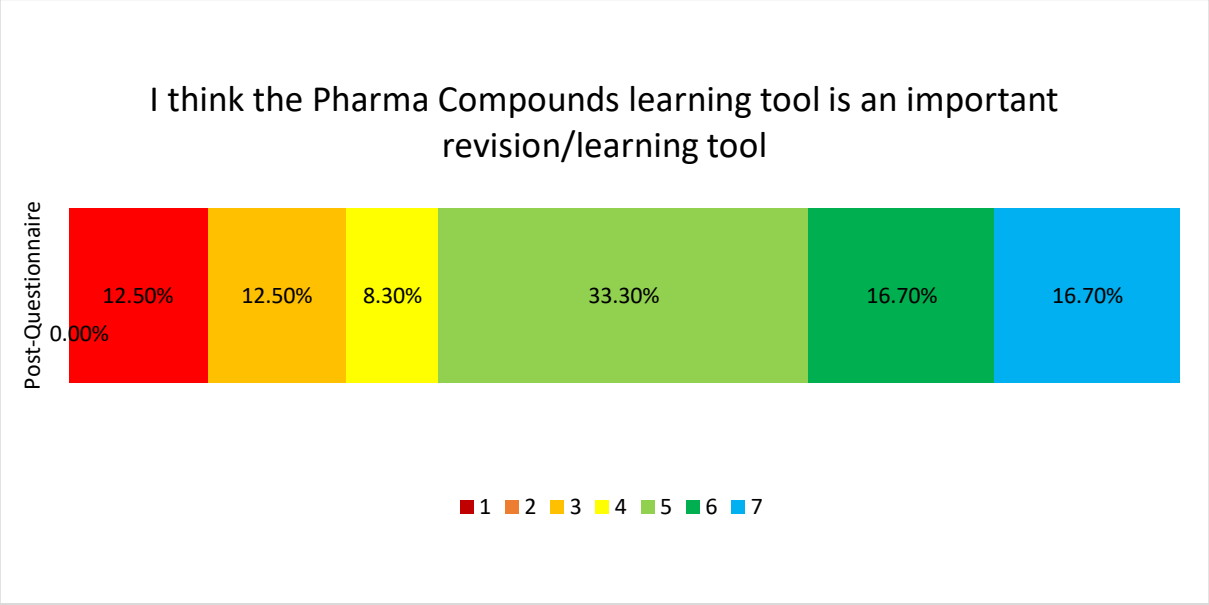


Figure 8.23 shows that the participants showed varying degrees of agreement with this Likert statement – 66.7% scored their agreement as being anchor points 5, 6 or 7. The only anchor points selected that had a degree of disagreement with the statement were points 2 and 3, each with 12.5%.

Statement 13: I believe using the Pharma Compounds learning tool could be beneficial to me

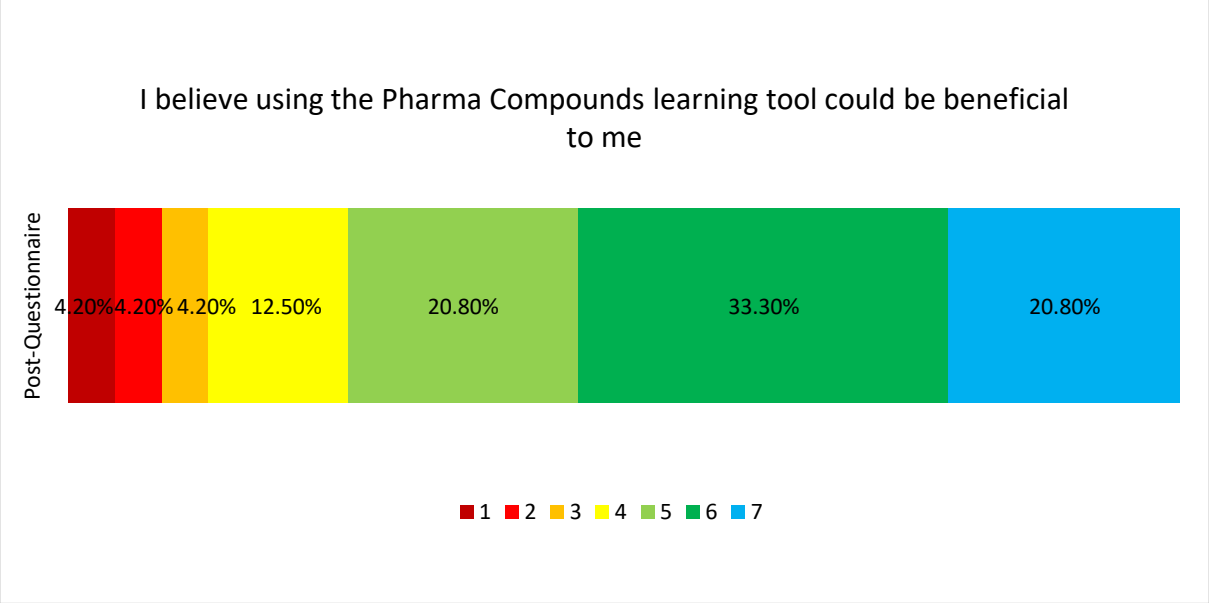


Figure 8.24 illustrates that a substantial proportion of post-questionnaire participants agreed with this Likert statement. 74.9% scored their agreement as either a 5, 6 or 7. 4.2% of the participants scored their level of agreement as 1, 2 or 3.

Statement 14: I would be willing to use the Pharma Compounds learning tool again because it has some value to me

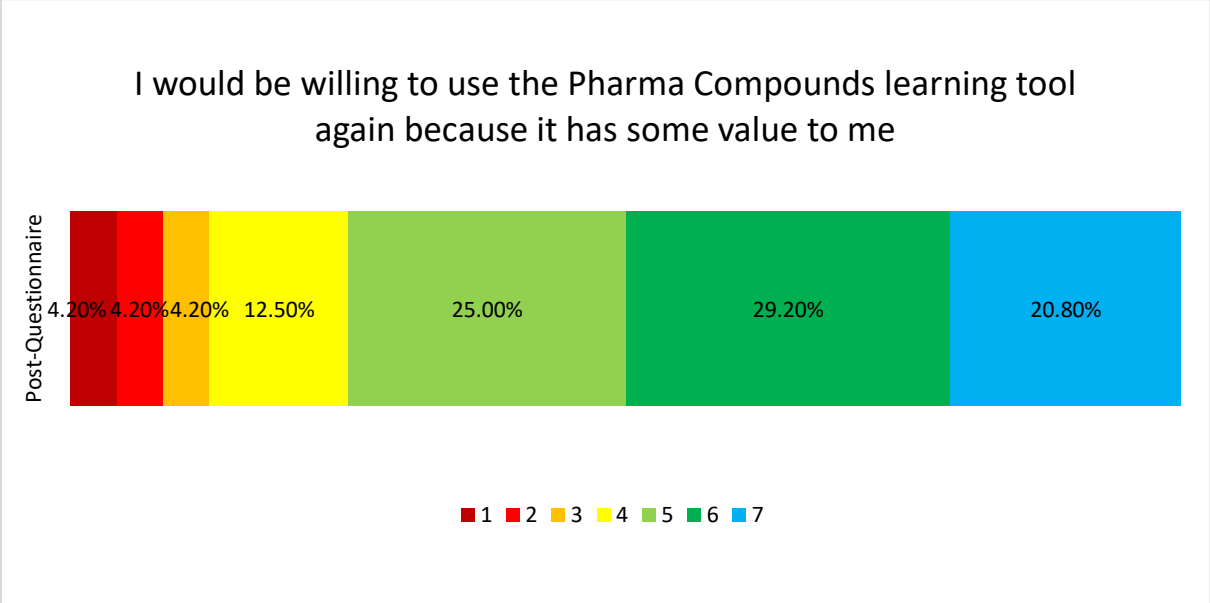


Figure 8.25 illustrates that the proportion of this Likert statement was very similar to the previous one. 75% of students scored their level of agreement as either a 5, 6 or 7. 4.2% of the remaining participants scored their agreement as either 1, 2 or 3.

The sixth form pre- and post- questionnaire IMI Likert statement result presents generally favourable attitudes towards the Pharma Compound AR tool. Sixth form students were in greater agreement with the positive Likert statements that pertained to the AR educational tool as opposed to statements that related to their conventional learning methods. In relation to the negatively worded IMI Likert statements (statements 6 and 8), participants were in greater disagreements with the Pharma Compounds statements when compared to the statements focuses on their conventional methods. Generally, sixth form students agreed that the educational AR tool was enjoyable to used and also agreed that it had importance and usefulness to their learning.

8.3.4 Comparison of IMI Agreement Scores

Of the 63 sixth form students who completed the pre-intervention questionnaire, 23 also completed the post-questionnaire. The agreement scores of the adjusted intrinsic

motivation inventory from both questionnaires are tabulated in appendix 46 for comparison.

The results illustrate that 60% of participants were in greater agreement when the Pharma Compounds tool was described as enjoyable as opposed to their agreement when their conventional methods were described as enjoyable (IMI statement 1). 57% of students were in greater agreement with having thoughts of enjoyment when using the AR tool compared to their level of agreement of having thoughts of enjoyment when using their conventional methods (IMI statement 2). 13% of students had greater level of agreement in relation to the AR tool helping improve their academic performance as opposed to their agreement with their conventional methods improving their performance (IMI statement 3). 70% of participants had greater agreement with the AR tool being described as interesting compared to their level of agreement to their conventional methods being described as interesting (IMI statement 4). 52% of students were in greater agreement to the AR tool holding value compared to their agreement of their conventional learning methods holding value (IMI statement 5). 35% of participants had a greater level of agreement with the Pharma Compounds AR tool holding their attention as opposed to their agreement with their conventional learning methods holding their attention (IMI statement 6). 65% of participants had higher agreement with the AR tool being described as fun to use compared to their agreement of their conventional learning methods being described as fun to use (IMI statement 7). 65% of students were in greater disagreement to being bored when using the AR tool compared to their level of disagreement to being bored when using the conventional learning methods (IMI statement 8). 52% of participants had higher levels of agreement when the Pharma Compounds AR tool was described as important to use to

develop visualisation skills compared to their level of agreement with their conventional methods being able to improve visualisation skill (IMI statement 9). Finally, 65% of participants were in greater agreement when the AR tool was described as enjoyable as opposed to their level of agreement to their current learning methods being described as enjoyable (IMI statement 10).

8.4 Undergraduate MPharm Questionnaire Response Rates and Demographic Results

In total, 68 Undergraduate MPharm students from Keele University consented to participate in the completion of both the pre- and post-intervention questionnaires. All 68 consenting participants completed the pre-questionnaire; 30 then completed and submitted the post-questionnaire after the intervention period. Table 8.8 below displays the response rates and demographic data for Undergraduate MPharm students.

		Consented	Pre-Questionnaire	Post-Questionnaire
Total Number of Students (RR%)		68	68 (100%)	30(44.1%)
Gender	Male	20	20 (29.4%)	9 (30.0%)
	Female	48	48 (70.6%)	21(70.0%)
	Prefer not to say	0	0 (0%)	0 (0%)
Age	18-21 years	56	56 (82.4%)	25 (83.3%)
	22-25 years	8	8 (11.8%)	3 (10.0%)
	25+ years	4	4 (5.9%)	2 (6.7%)
	Prefer not to say	0	0 (0%)	0 (0%)
Type of Students	Domestic	64	64 (94.1%)	26 (86.7%)
	International	4	4(5.9%)	4 (13.3%)

Table 8.7 displays the response rates for Undergraduate MPharm students' pre- and post-questionnaires.

Similar to the trend seen in the year 12 students' response rates, the number of participants who submitted responses fell from 100% in the pre-questionnaire to 44.1% in the post-questionnaire. The proportion of male and female participants across the pre- and post-questionnaire was almost identical. Similarly, the proportions of participants from the different age categories were almost identical in both questionnaires. The proportion of

domestic students fell from 94.1% in the pre-questionnaire to 86.7% in the post, whereas the international student proportion rose from 5.9% to 13.3%. Nearly one-quarter of the pre-questionnaire participants had previously been involved in some type of research, while this figure rose to one-third with the post-questionnaire participants.

8.5 Undergraduate MPharm Questionnaire Results

8.5.1 Internal Consistency

A Cronbach α score of 0.72 was obtained for the pre-questionnaire scale regarding motivation towards learning in different learning environments. The pre- and post-questionnaire adapted IMI scales generated overall Cronbach α scores of 0.87 and 0.91, respectively (scores above 0.7 are considered to be acceptably reliable). These values indicate a high-reliability level within each of the scales included in both questionnaires (Chapter 4.6.1). The Cronbach α scores of the individual motivation and usefulness subscales used in both the pre- and post-questionnaires are also listed below in table 8.9.

	Pre-questionnaire Cronbach alpha score (a)	**Post-questionnaire Cronbach alpha score (a)**
Motivation in different learning sessions	0.72	n/a
IMI Motivation	0.71	0.88
IMI Usefulness	0.81	0.93
Overall IMI (motivation and usefulness)	0.87	0.91

Table 8.8 displays Cronbach alpha scores of the various scales included in undergraduate students' pre- and post-intervention questionnaires.

8.5.2 Descriptive and Inferential Statistics

The results of the Likert type statements of both the pre- and post-intervention questionnaires were analysed by calculating the median values (Chapter 5.8.1). Table 8.10 details the median scores for seven Likert style questions included in the pre-questionnaire.

These questions required students to rank their agreement with the use of technology in education and their self-reported motivation when involved in teaching sessions of different styles.

Undergraduate MPharm participants had a median score of 4 (agree) when scoring their agreement with using mobile devices in teaching sessions. A median score of 4 (important) was also recorded when students were asked to rank the level of importance technology holds in their education. Four of the six Likert style statements that required students to rank their self-reported motivation levels in different styled teaching sessions generated a median score of 4. The remaining two statements that focused on motivation in laboratory sessions and lectures scored a median motivation score of 3 (neither).

Question/Statement	Pre-questionnaire Median Score
Do you agree with the use of mobile devices (tablets, smartphones etc.) in teaching sessions?	4
How important to you is the use of technology in education?	4
How would you rate your motivation towards learning while using computer-generated simulations?	4
How would you rate your motivation towards learning while in demonstration?	4
How would you rate your motivation towards learning while in laboratory sessions?	3
How would you rate your motivation towards learning while in lectures?	3
How would you rate your motivation towards learning while in workshops?	4
How would you rate your motivation towards learning when revising using your current methods?	4

Table 8.9 displays the median scores from the pre-questionnaire Likert type statements of students' self-reported motivation in each type of teaching session.

Concerning the post-questionnaire Likert style questions, participants scored a median score of 4 (easy) when asked to rank how easy/difficult the AR educational tool is to use. A median score of 4 (easy) was also recorded when students rated their ability to visualise learning material after using the AR tool. The median score reported by participants in

relation to the frequency with which they used the Pharma Compounds system was '1', between once and twice weekly.

Question/Statement	Post-questionnaire Median Score
How difficult/easy did you find the Pharma Compounds learning tool to use?	4
On average, how many times a week did you use the Pharma Compounds learning tool?	1
How would you rate your ability to visualise similar learning material after using the AR Pharma Compounds learning tool?	4

Table 8.10 Displays the median scores for the post-questionnaire non-IMI Likert style questions.

Table 8.12 details the individual median scores from pre- and post-intervention adapted IMI Likert statements (IMI Likert statements are listed in section 8.5.3.5). A score of 1=not true at all, 4=somewhat true, and 7=very true. IMI statements 1,2,4, 5, 7, 9 and 10 display an increase in participants' agreement when comparing post- and pre-intervention scores. Only one statement, 6(R), showed a lower score in the post-questionnaire compared to the pre-questionnaire.

IMI statement	Pre-Questionnaire Median Score	Post-Questionnaire Median Score	Wilcoxon Signed-Rank test p-value
1	4	5	0.178
2	3	4	0.087
3	5	5	0.735
4	4	6	0.000*
5	5	6	0.329
6 (R)	3	3	0.039*
7	4	6	0.000*
8 (R)	4.5	3	0.000*
9	4	5.5	0.004*
10	4	5	0.001*
11	-	6	-
12	-	5	-
13	-	5.5	-
14	-	5	-

Table 8.11 displays both the pre- and post-intervention individual median and mean scores of the IMI statements for Year 12 students. *Statistical significance reached p<0.05.

Six of the ten IMI Likert statements that appear on both the pre- and post-intervention questionnaires were found to have a significant difference between the paired scores before and after the intervention period ($p<0.05$) – statements 4, 6(R), 7, 8(R), 9 and 10. The remaining statement did not show significant differences between the paired pre- and post-questionnaires ($p>0.05$).

The scores of the adapted IMI Likert statements underwent the same analytical process as those gathered from the Year 12 biology and chemistry students. Initially, the statements branded with '(R)' were reverse scored (Likert score subtracted from 8) (section 8.3.2). Then the individual Likert statements were grouped into their relevant subscale, and the average agreement scores were calculated (chapter 5.8.1). The results of this analysis are tabulated below in table 8.13 and illustrate that, on average, participants responded with a higher agreement to the IMI post-questionnaires Likert statements.

	Mean Pre-Question Score	Mean Post-Questionnaire Score
Interest/Enjoyment (Motivation)	3.97	5.15
Usefulness/Value	4.94	5.29

Table 8.12 Displays the mean motivation and usefulness score for both pre- and post-intervention questionnaires (means for all submitted pre- and post-intervention questionnaires)

A dependent t-test was performed on the pre- and post-intervention means from the IMI subscales. A significant difference was found between the interest/enjoyment subscale when comparing the means from the pre- and post-intervention questionnaires ($t_{(30)}$ = -5.839, $p<0.05$). As a result, the null hypothesis can be rejected as the interest/enjoyment subscale is a viable tool to measure self-reported intrinsic motivation (section 5.7.1) - There is no significant difference in self-reported motivation towards learning after using the AR Pharma Compounds tool. Therefore, the use of the Pharma Compound AR system can improve the self-reported intrinsic motivation towards learning of Undergraduate MPharm students when used in their educational studies. The second IMI subscale, usefulness/value, did not show any significant differences between the means of the pre- and post-intervention questionnaires ($t_{(30)}$ = -1.562, $p>0.05$).

8.5.3 Percentage distribution of Likert Type and Likert Scale scores

As with the Likert statement responses from Year 12 students, the responses collected from MPharm Undergraduate students were analysed to understand the percentage distributions of responses across each Likert point. Figures 8.26 to 8.33 display the distribution of the pre-questionnaire non-IMI Likert statements followed by the post-questionnaire non-IMI Likert statements in figures 8.34 to 8.36. Finally, figures 8.37 to 8.50 illustrate the side-by-side response distribution for each IMI Likert statement on the pre- and post-questionnaire.

8.5.3.1 Pre-Questionnaire

Question 1 - Do you agree with the use of mobile devices (tablets, smartphones etc.) In teaching sessions?

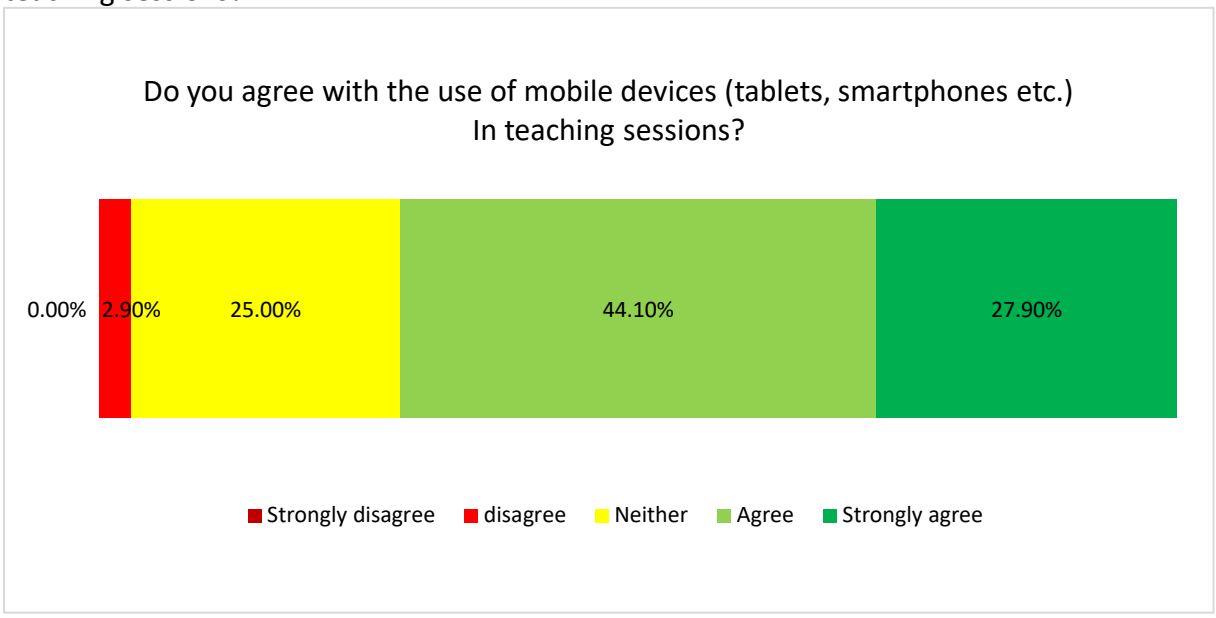


Figure 8.26 illustrates that most undergraduate MPharm participants agree with using mobile devices in teaching sessions – 72% either 'agree' or 'strongly agree'. Only 2.9% of MPharm participants 'disagree' with this statement.

Question 2 - How important to you is the use of technology in education?

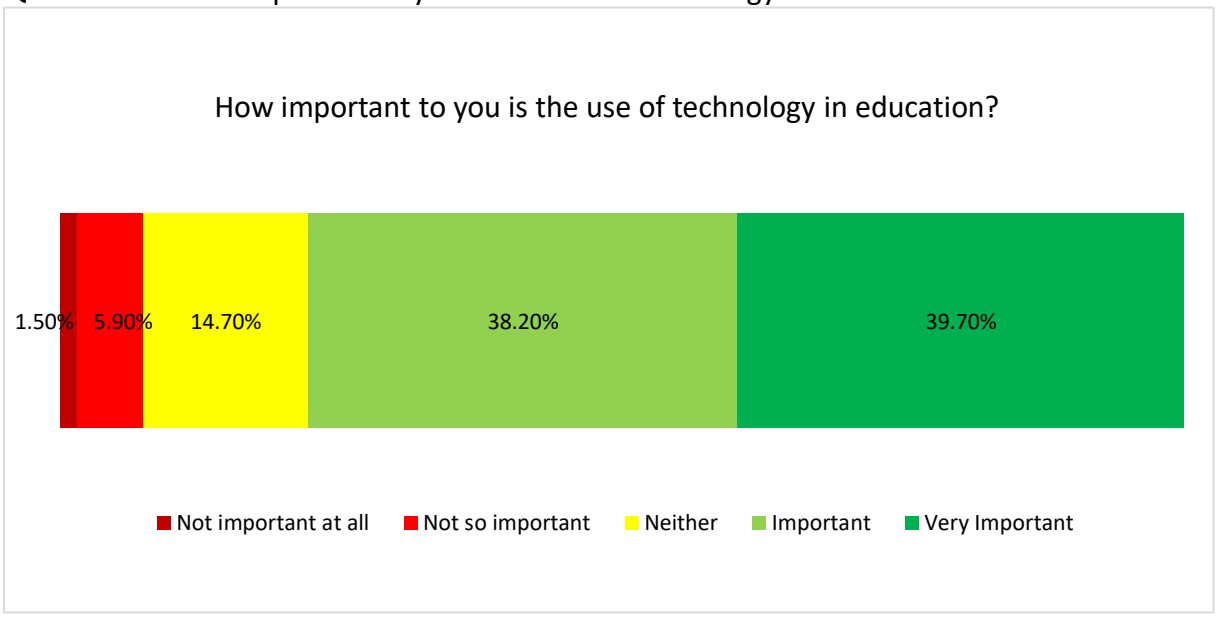


Figure 8.27 illustrates that over 50% of participants feel using technology in education is either 'important' or 'very important' (77.9%). Conversely, only 7.4% of MPharm participants believe using technology in education is either 'not important at all' or 'not so important'.

Question 3 - How would you rate your motivation towards learning while using computer-generated simulations?

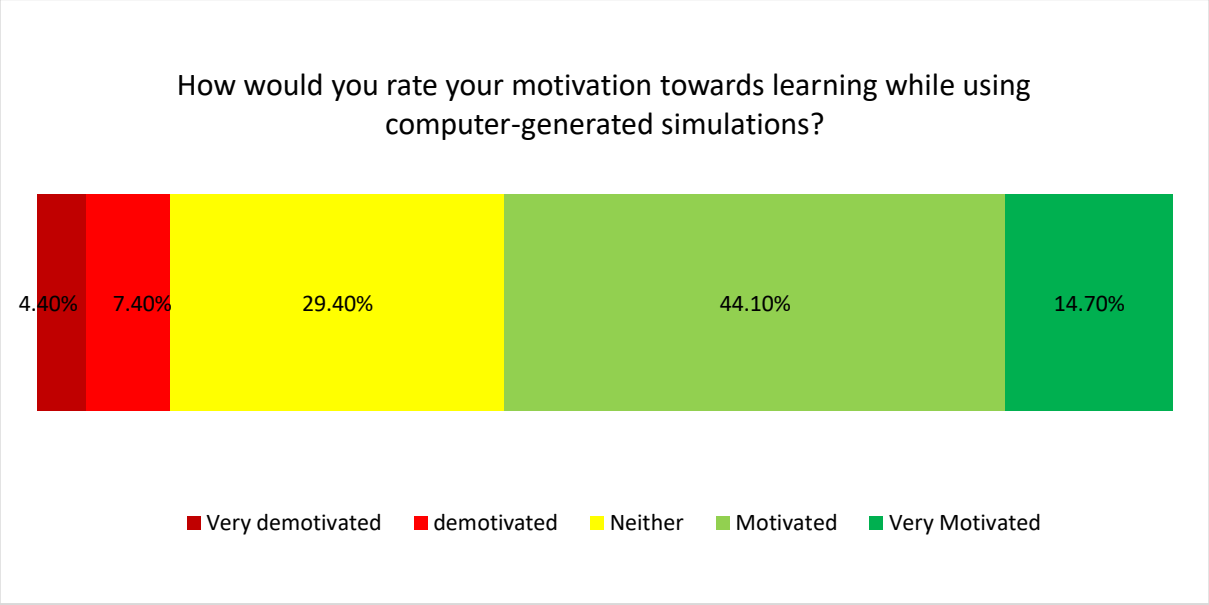


Figure 8.28 shows that the largest proportion of students feel 'motivated' in sessions that utilise computer-generated simulations (44.1%). The next largest anchor point selected was 'Neither' (29.4%), followed by 'very motivated' (14.7%). 'Very demotivated' was the least selected anchor point with 4.4% of participants.

Question 4 - How would you rate your motivation towards learning while in demonstrations?

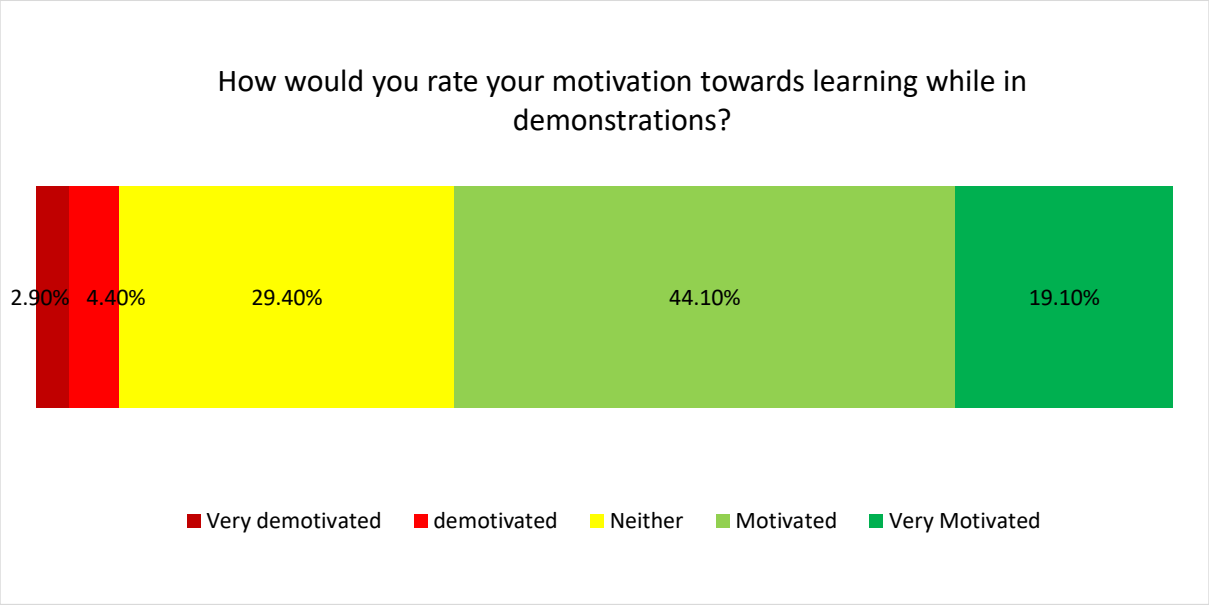


Figure 8.29 illustrates that most MPharm students are either 'motivated' or 'very motivated' when demonstrations are utilised in teaching sessions (63.2%). However, on the opposite end of the Likert scale, 7.3% of participants believe that they either feel 'demotivated' or 'very demotivated' in these teaching sessions.

Question 5 - How would you rate your motivation towards learning while in laboratory sessions?

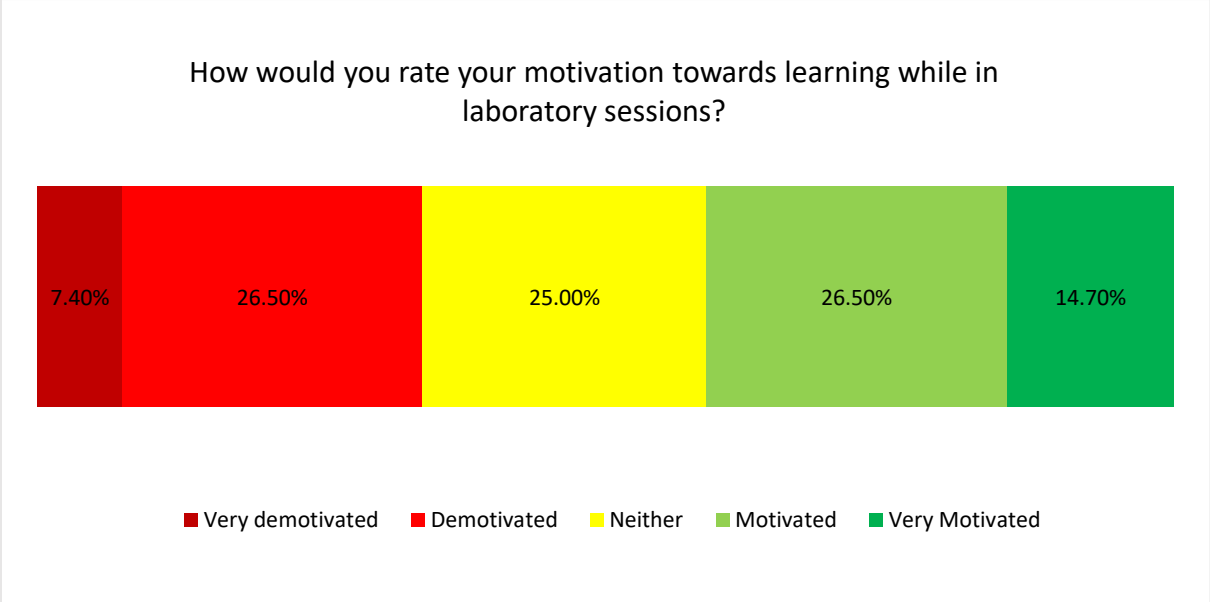


Figure 8.30 illustrates the motivation of students when in laboratory sessions. The distribution across the middle three anchor points, 'demotivated', 'neither', and 'motivated', are almost identical – 26.5%, 25% and 26.5%, respectively. The 'very motivated' (14.7%) anchor point had almost double the percentage of MPharm students as the 'very demotivated' anchor point (7.4%).

Question 6 - How would you rate your motivation towards learning while in lectures?

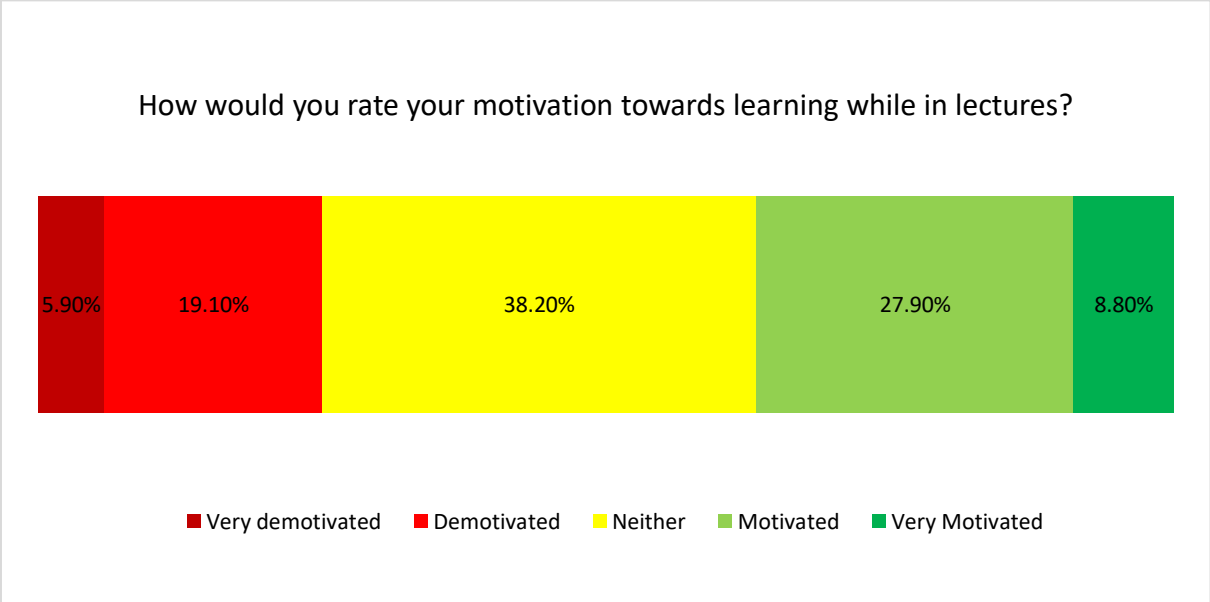


Figure 8.31 shows that the largest proportion of MPharm students were 'undecided' about whether they feel motivated or demotivated when in lectures (38.2%). The next largest proportion was seen to be the 'motivated' (27.9%) anchor point, followed by the 'demotivated' point (19.1%).

Question 7 - How would you rate your motivation towards learning while in workshops?

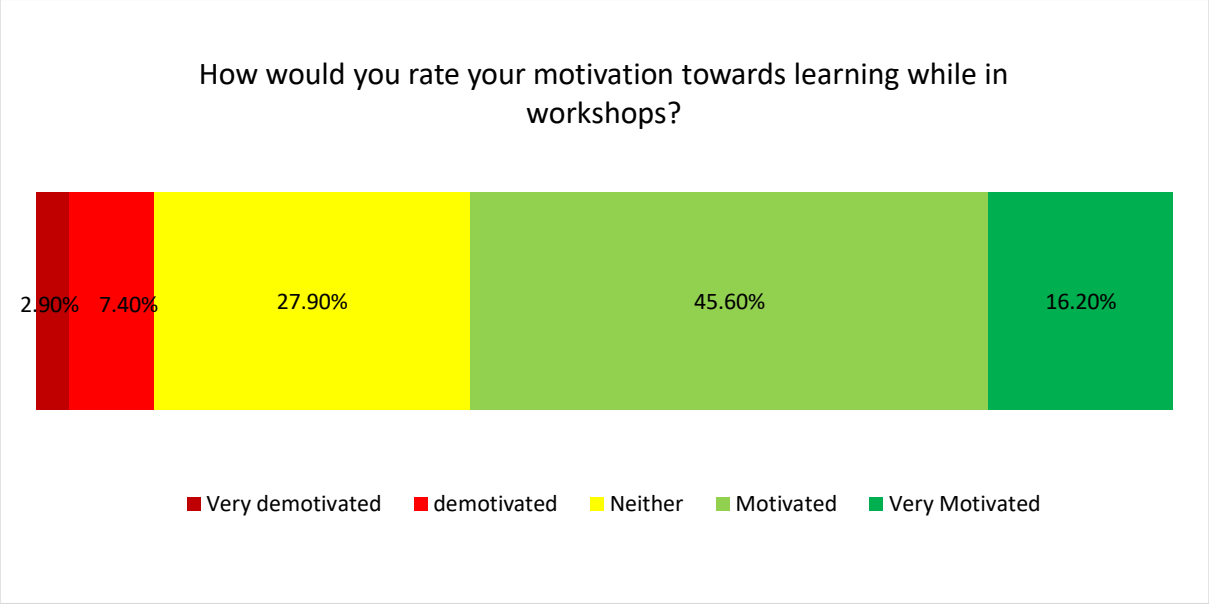


Figure 8.32 shows that almost 50% of MPharm students feel 'motivated' when in workshops, and a further 16.2% feel 'very motivated'. On the other hand, 7.4% of students selected the demotivated anchor point, with a further 2.9% feeling 'very demotivated' when in workshops.

Question 8 - How would you rate your motivation towards learning when revising using your current methods?

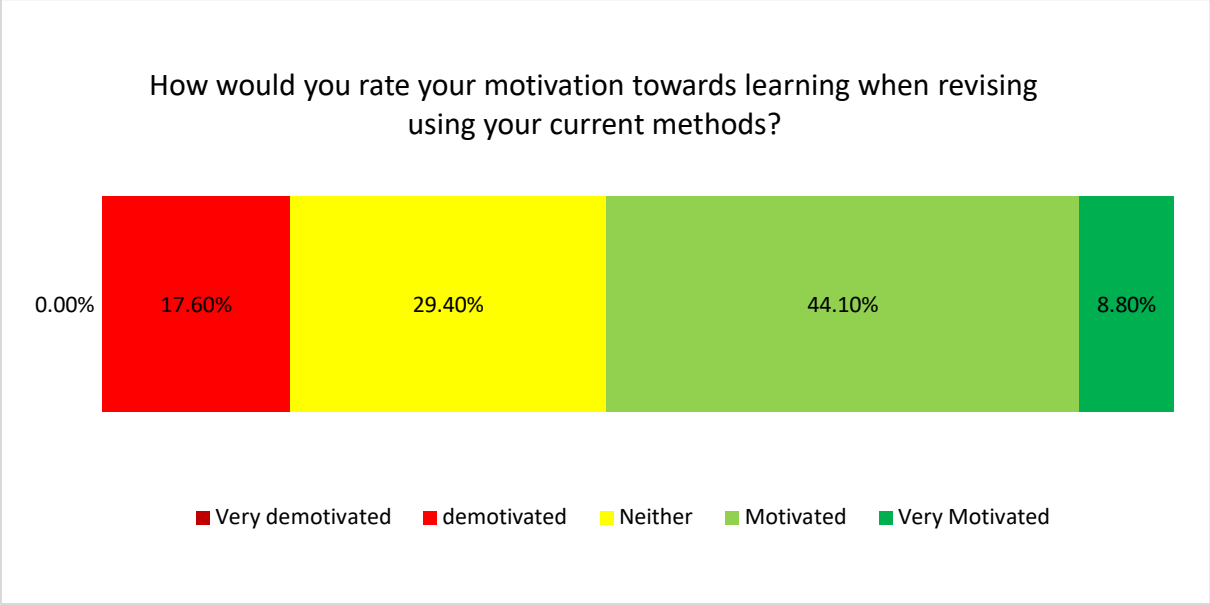


Figure 8.33 illustrates that over 50% of participants feel either 'motivated' or 'very motivated' (52.9%). 29.4% of students selected the 'neither' anchor point, and the remaining 17.6% of participants felt demotivated. Absolutely no student felt 'very demotivated' when revising.

The results of the pre-questionnaire Likert-statements above depict that the majority of undergraduate MPharm students were in favour of the use of mobile technology during their teaching sessions (statement 1) and believe that its use is important to their education (statement 2). Over half of MPharm participants believe they are motivated or very motivated to learn when in teaching sessions that utilise computer generated simulations (statement 3), demonstrations (statement 4), workshops (statement 7) and revision sessions (statement 8). In relation to the reported motivation of MPharm students when in laboratory sessions (statement 5) and lectures (statement 6), just over 30% and 25% reported to be either demotivated or very demotivated respectively.

8.5.3.2 Post-Questionnaire

Question 1 - How difficult/easy did you find the Pharma Compounds learning tool to use?

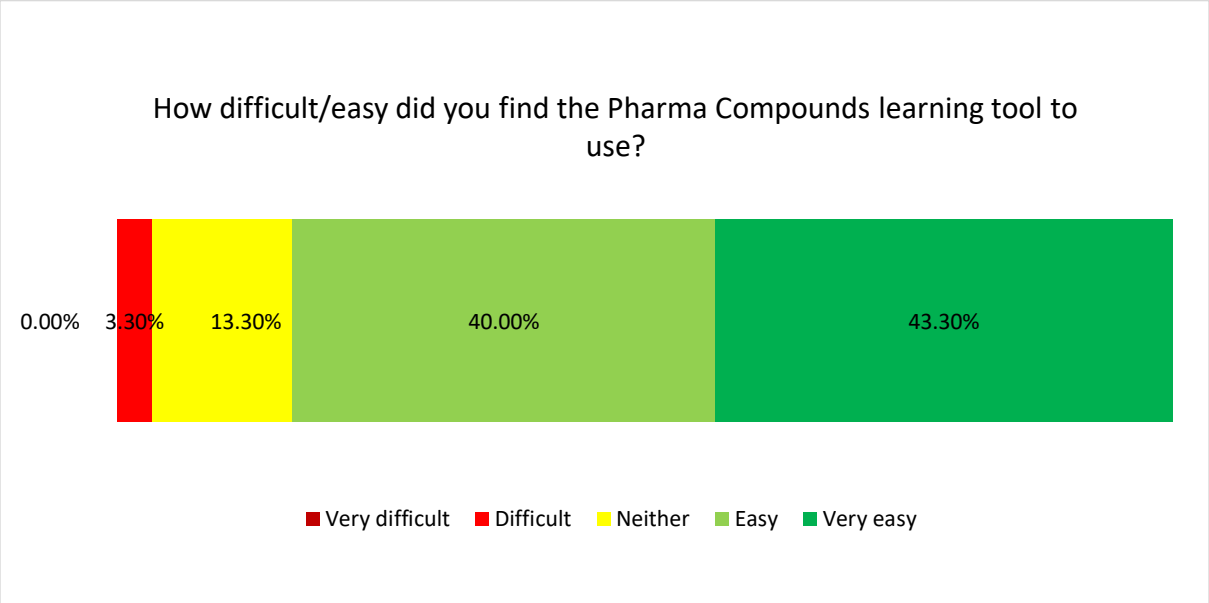


Figure 8.34 illustrate that the overwhelming majority of students find the Pharma Compounds learning tool either 'easy' or 'very easy' to use (40% and 43.3%). Only 3.3 % of MPharm participants felt the AR system was difficult to use, and the remaining 13.3% were undecided (neither).

Question 2 - On average, how many times a week did you use the Pharma Compounds learning tool?

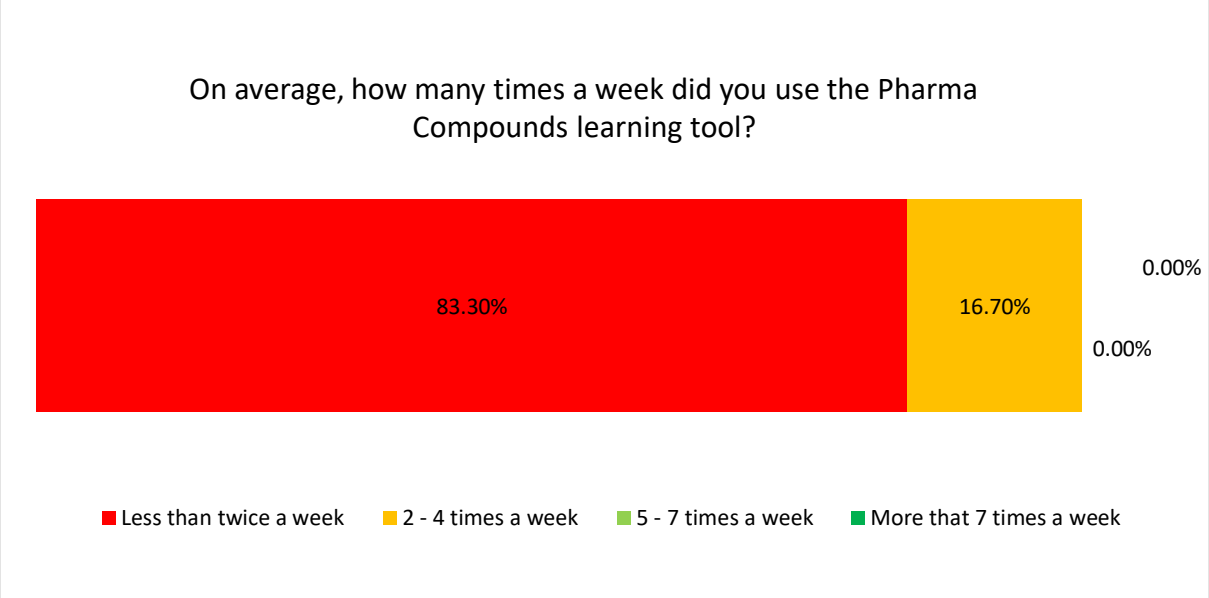


Figure 8.35 shows that all participants use the AR learning tool either 'less than twice a week' or '2 – 4 times a week'. 83.3%of MPharm students used the app less than twice a week. The remaining 16.7% use the learning tool 2 – 4 times a week.

Question 3 - How would you rate your ability to visualise similar learning material after using the AR Pharma Compounds learning tool?

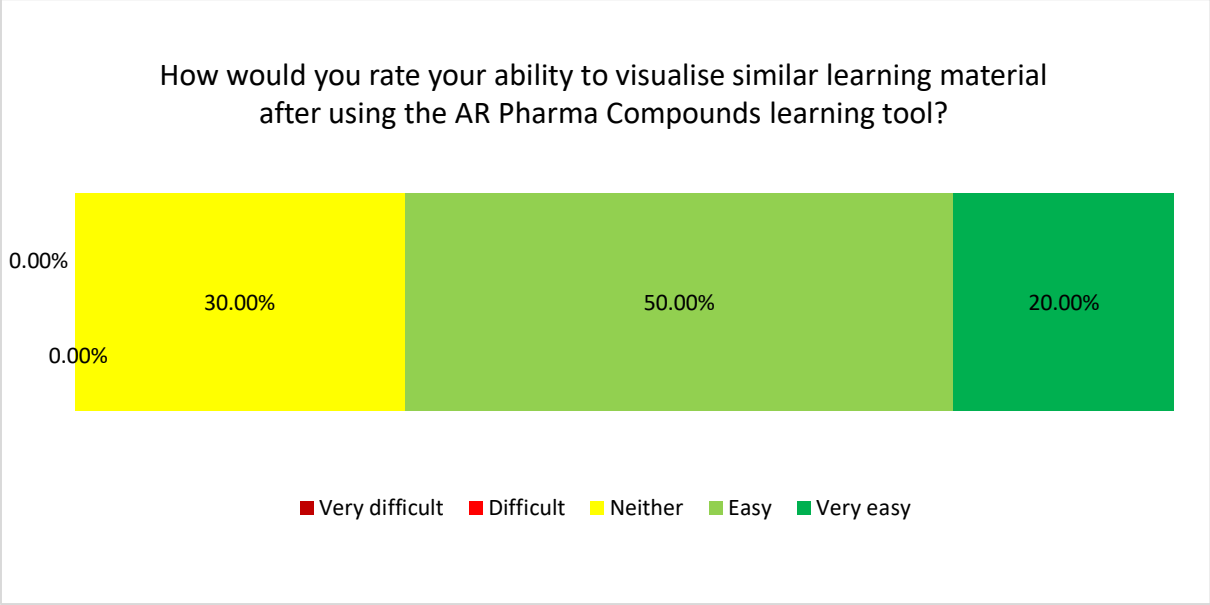


Figure 8.36 illustrates that after using the Pharma Compound AR system, 70% of students found visualising learning material either 'easy' or 'very easy'. The remaining 30% of participants were undecided (neither). No participant felt visualising learning material was 'difficult' or 'very difficult'.

The overwhelming majority of MPharm students reported on the post-questionnaire that the Pharma Compounds AR educational tool was either easy or very easy to use (statement 1) however only reported to have used the tool less than twice a week (statement 2). Only a small proportion of students reported to have used the tool between two and four times weekly. With that, not a single MPharm participant reported to have difficultly visualising learning material after the use of the AR educational tool – The vast majority reported to find visualisation either easy or very easy (statement 3).

8.5.3.3 Pre and Post Questionnaire IMI scales

As with the sixth form IMI Likert results, the percentage distribution of responses to each IMI statement included in either the pre- or post-intervention is displayed below. Pre- and post-questionnaire IMI statements 1 to 10 are presented side-by-side for direct comparison.

Statements 11 to 14 were only present in the post-questionnaire and focused on the usefulness of the intervention tool and therefore presented individually.

Stage 2 MPharm students demonstrated a higher degree of agreement to statements that focused on enjoyment, and thus motivation, towards learning when the statement referred to the Pharma Compound AR learning tool rather than conventional methods of learning. A similar trend was evident in the Likert statements related to the intervention tool's usefulness.

Likert scale anchor points

Not true at all			**Somewhat true**			**Very true**
1	2	3	4	5	6	7

Statement 1: I enjoy my current learning/revision methods very much - I enjoyed using the Pharma Compounds learning tool very much

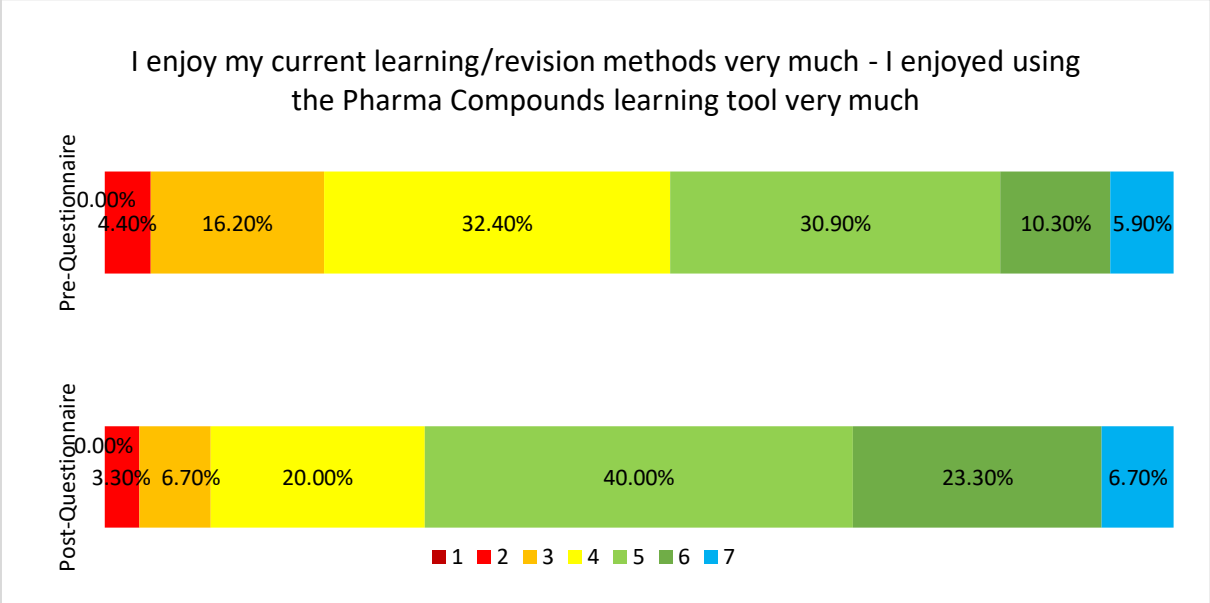


Figure 8.37 shows that both the pre- and post-responses to this Likert statement follow the same trend; both are skewed towards 'very true'. The pre 47.1% of participants who completed the pre-questionnaire scored the statement as either '5, 6 or 7' compared to 70% in the post-questionnaire. The larger proportion of responses in the pre-question was point '4' (32.4%), whereas anchor point '5' (40%) was the largest in the post-questionnaire.

Statement 2: While I learn/revise using my current methods, I think about how much I enjoyed it - While using the Pharma Compounds learning tool, I was thinking about how much I enjoyed it

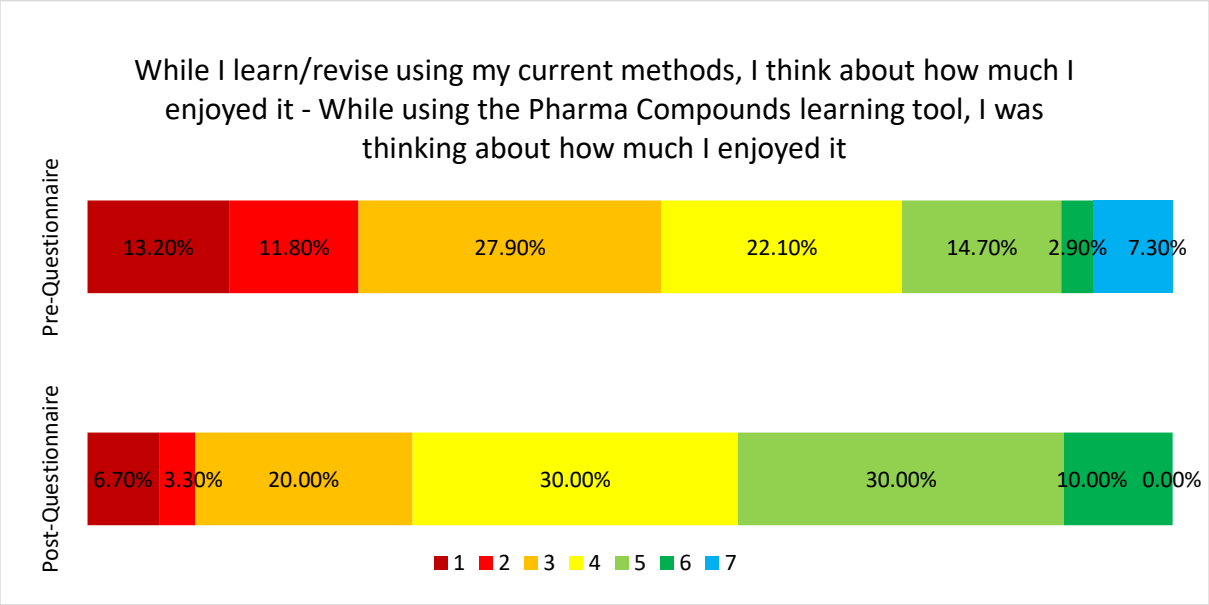


Figure 8.38 shows that on the pre-questionnaire, the largest proportion of MPharm participants chose anchor point '3', and the majority of students did not agree with the statement with varying degrees – 52.9% of participants selected either point '1, 2 or 3'. A further 22.1% of students felt the statement was 'somewhat true' (point 4). The largest proportion of responses selected was either anchor point '4' or '5' (both 30%), with 40% of participants selecting either point '5' or '6' – point '7' was not selected by any participant in the post questionnaire.

Statement 3: I think using my current learning/revision methods could help me to improve my academic performance - I think using the Pharma Compounds learning tool could help me to improve my academic performance

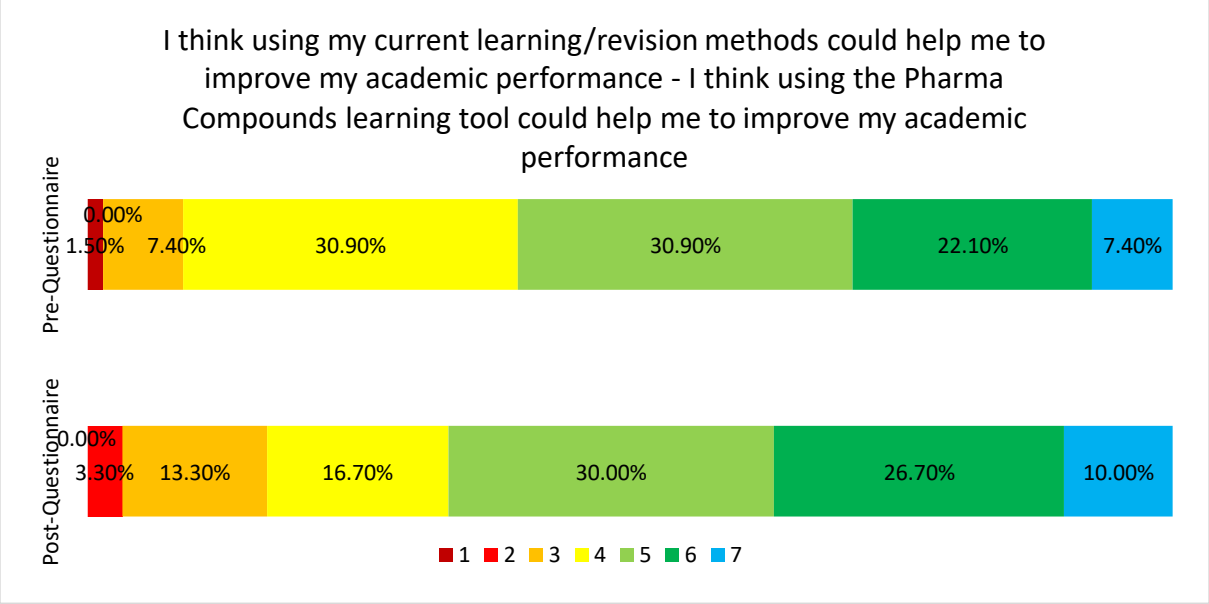


Figure 8.39 illustrates that responses to this statement on both the pre- and post-questionnaires follow similar trends. Over 50% of participants selected either points '5, 6 or 7' on both questionnaires – 30.9%, 22.1% and 7.4%, respectively for the pre-questionnaire, and 30%, 26.7% and 10% for the post-questionnaire. Only 8.9% of participants in the pre-questionnaire did not agree with this statement; this figure was 16.6% for the post-questionnaire

Statement 4: I would describe my current learning/revision methods as very interesting - I would describe the Pharma Compounds learning tool as very interesting

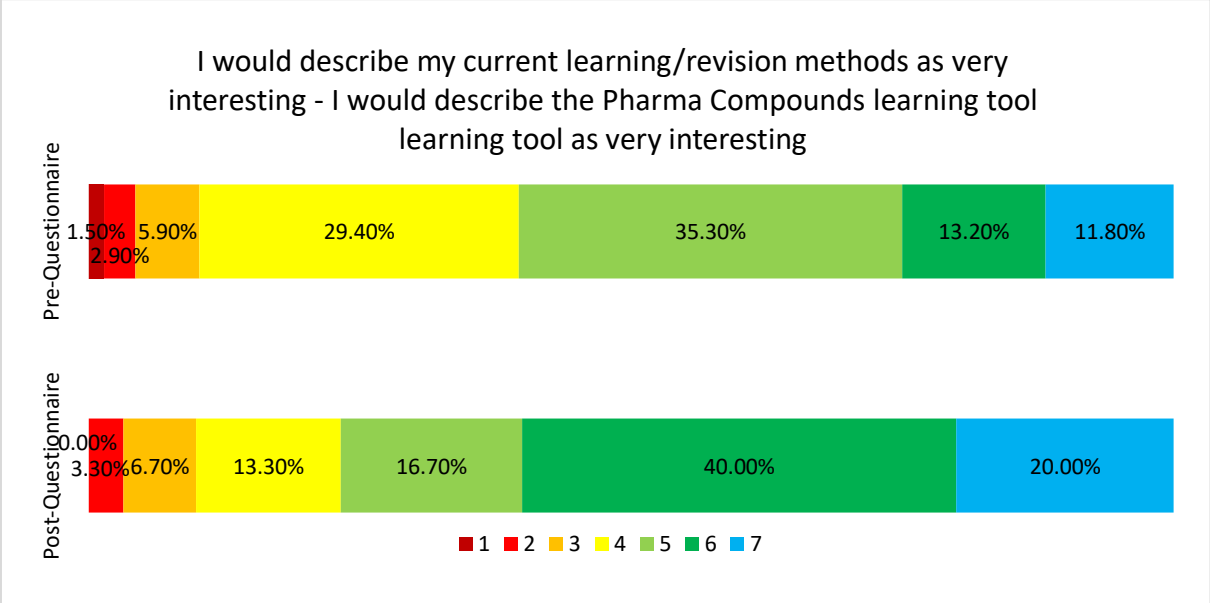


Figure 8.40 shows that most responses to this Likert statement in both questionnaires were skewed towards 'very true'. The largest proportion of responses from the pre-questionnaire was for anchor point 5 (35.5%), followed by points '4' and '6' (29.4% and 13.2%), respectively. The largest proportion of responses seen in the post-questionnaire was anchor point '6' (40%) followed by points '7' (20%) and '5' (16.7%).

Statement 5: I believe my current learning/revision methods are of some value to me - I believe the Pharma Compounds learning tool could be of some value to me

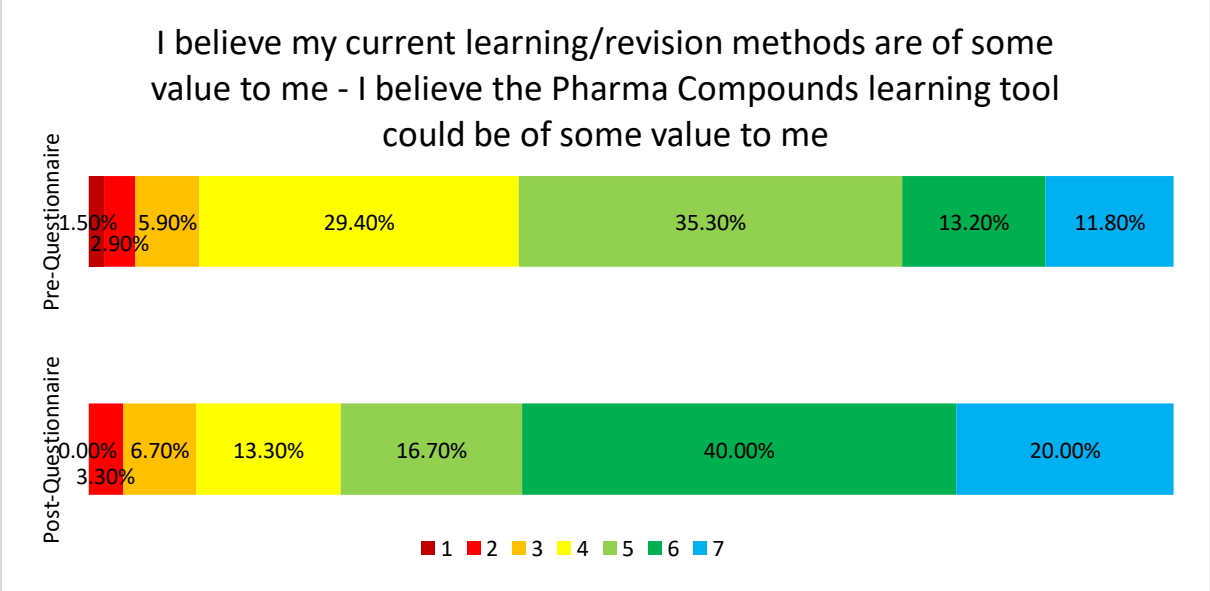


Figure 8.41 illustrates that the largest proportion of responses seen in the pre-questionnaire was for anchor point '5' (35.3%), followed by point '4' (29.4%), whereas the largest proportion of responses in the post-questionnaire was for anchor point '6' (40%) followed by point '7' (20%) and '5' (16.7 %).

Statement 6: My current learning/revision methods do not hold my attention at all (R) - The Pharma Compounds learning tool did not hold my attention at all (R)

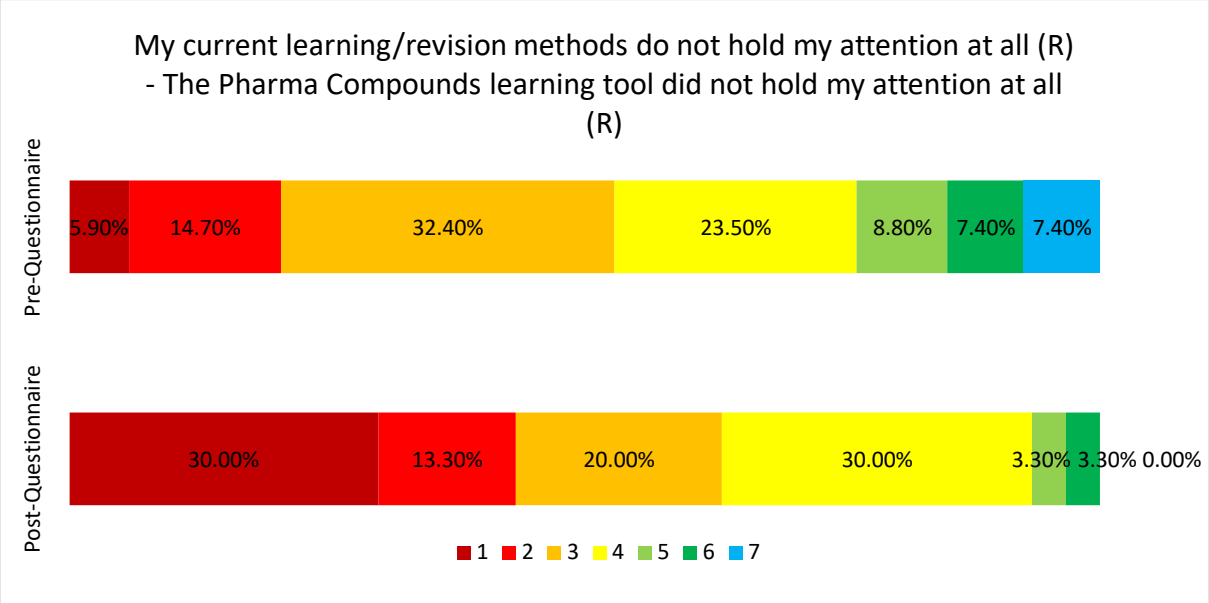


Figure 8.42 shows that the largest proportion of participants did not agree with this Likert statement after the intervention period compared to the pre-questionnaire responses. 30% of participants in the post-questionnaire chose anchor point '1' compared to 5.9% in the pre-questionnaire. 23.6% of participants in the pre-questionnaire agreed with this statement to some degree (points '5, 6 and 7'). This figure fell to 6.6% in the post-questionnaire – only points 5 and 6 were selected above the halfway anchor point.

Statement 7: My current learning/revision methods are fun to use - The Pharma Compounds learning tool was fun to use

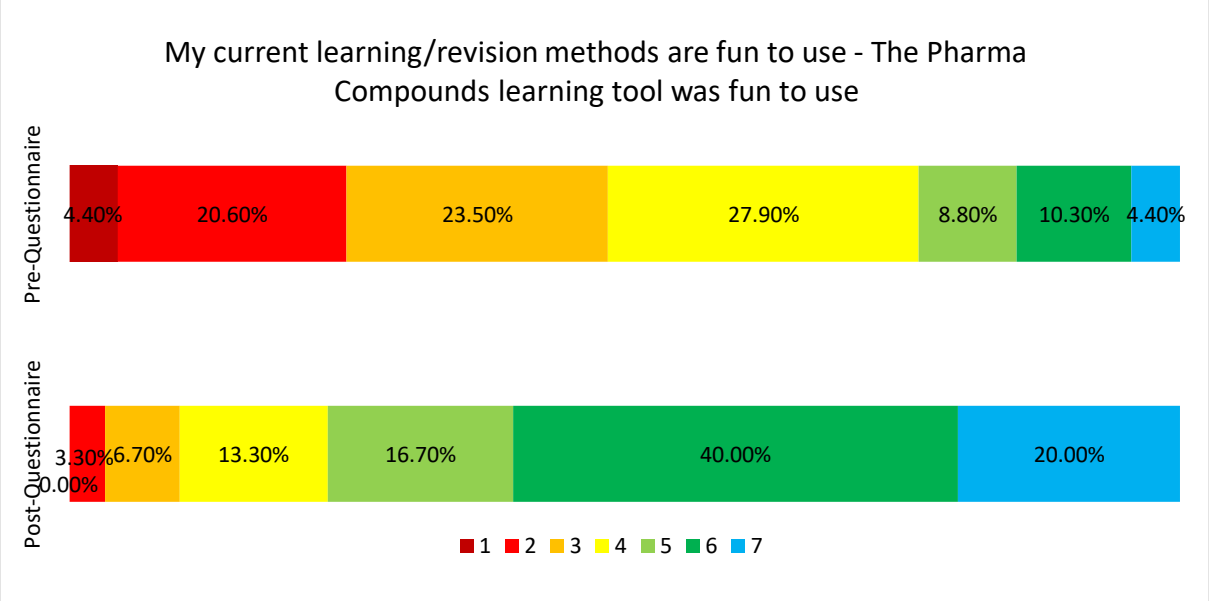


Figure 8.43 illustrates a great difference between the pre- and post-intervention questionnaires. A large proportion of the pre-questionnaire responses did not agree with this statement – 23.5% selected point '3', 20.6% selected point '2' and 1.4% selected point '1'. When compared to the post-questionnaire, the largest proportion of responses were skewed towards the 'very true' end of the Likert scale.

Statement 8: I think my current learning/revision methods are boring (R) - I thought the Pharma Compounds learning tool was boring (R)

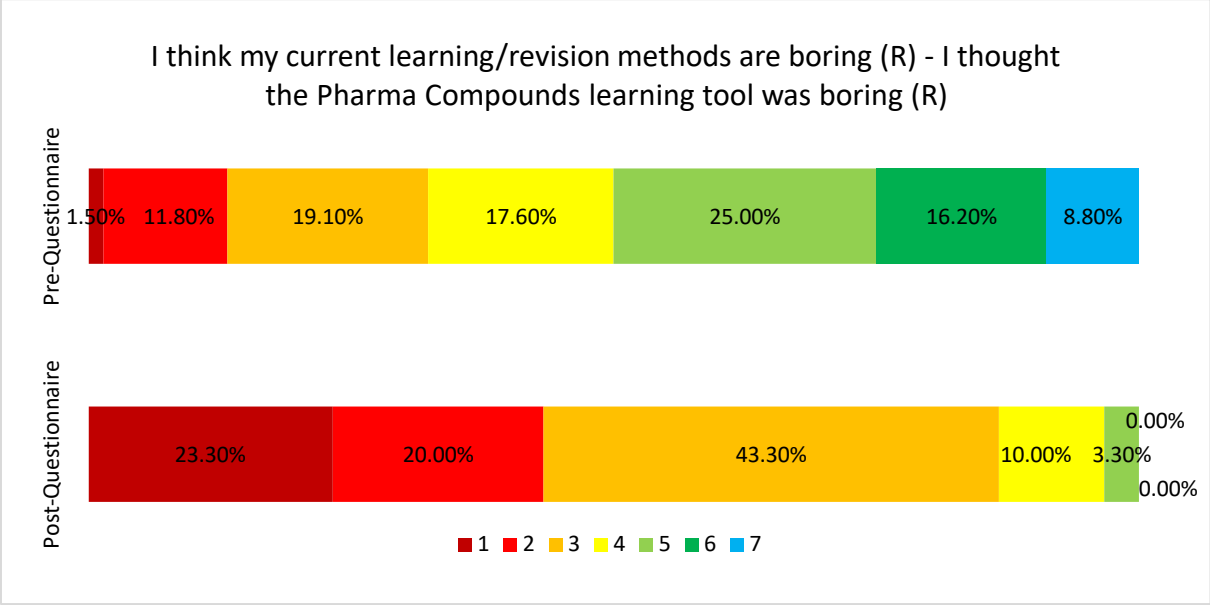


Figure 8.44 illustrates a difference between pre- and post-questionnaire Likert statement agreement. Half of the pre-questionnaire responses were skewed towards the 'strongly disagree' end of the Likert scale. 32.4% of participant responses had a degree of disagreement with the statement. The remaining 17.6% of participants remained undecided, selecting anchor point '4'. The post-questionnaire displays that almost 90% of participant responses disagreed with this Likert statement (Anchor points '1, 2 and 3'). Only 3.3% of participants agreed with the statement selecting anchor point '5'; the remaining 10% were undecided.

Statement 9: I think that it is important to use my current learning/revision methods because it can develop visualisation skills - I think that it is important to use the Pharma Compounds learning tool because it can develop my visualisation skills

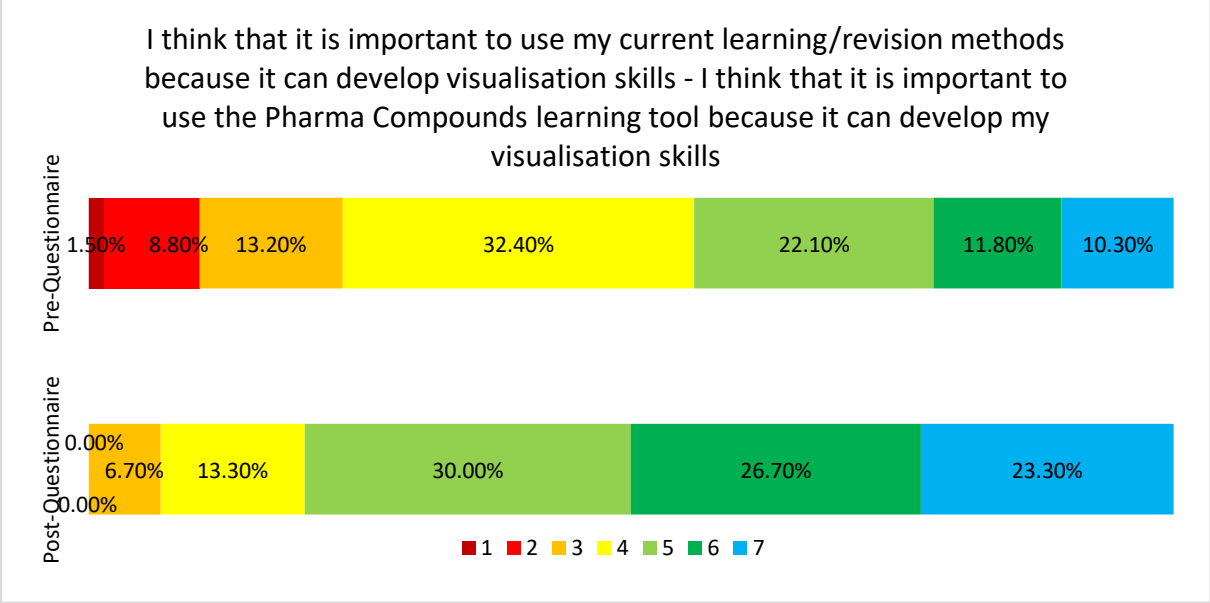


Figure 8.45 shows that both pre- and post-questionnaires share a similar skewness towards an agreement with the Likert scale. The largest proportion of pre-questionnaire responses was anchor point 4 (32.4%). Of the remaining responses, a large percentage agreed with the Likert statement (22.1%, 1.8% and 10.3% selecting anchor points '5, 6 and 7' respectively). The proportions of participants who agreed with this Likert statement grew in the post-questionnaire – 80% of responses were of varying degrees of agreement (30% selected point 5, 26.7% selected point 6 and 23.3% selected point 7).

Statement 10: I think my current learning/revision methods are quite enjoyable - I thought the Pharma Compounds learning tool was quite enjoyable

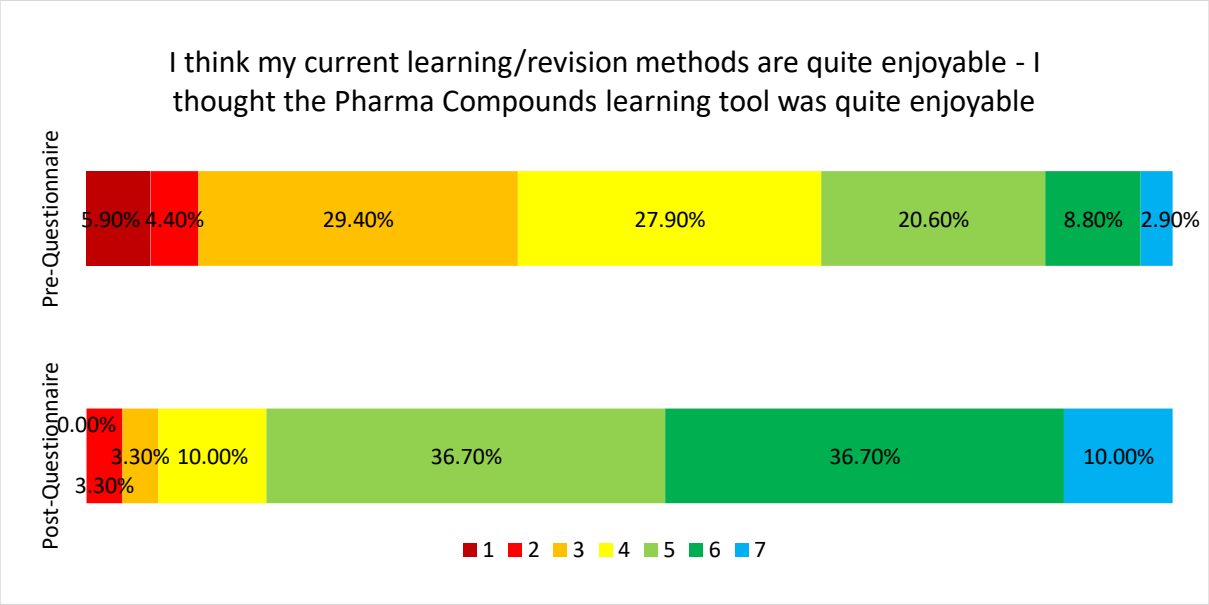


Figure 8.46 illustrates that the largest proportion of pre-questionnaire responses were deemed to be in disagreement with the statement; almost 40% of participants disagreed (anchor '1, 2 or 3'). Concerning the post-questionnaire, the largest proportion of responses agreed with the statement. 73.4% of participants selected anchor points '5' or '6'. A further 10% agreed, selecting the most extreme anchor point '7'.

Statement 11: I think the Pharma Compounds learning tool is useful for visualising difficult material

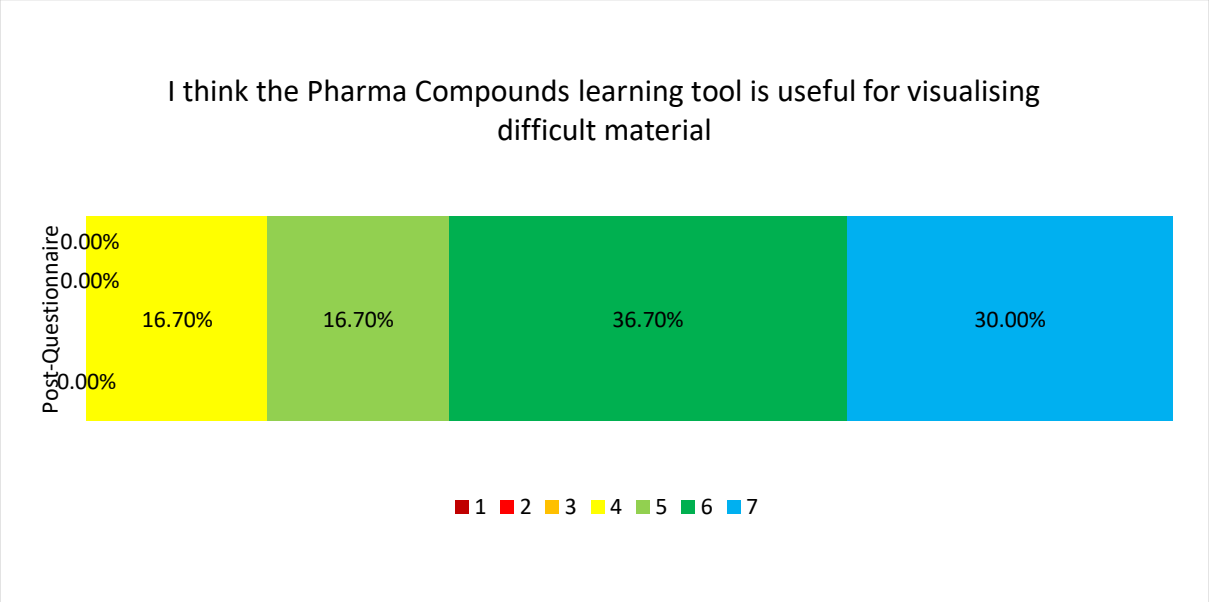


Figure 8.47 shows that all participants who responded to this statement either agreed or were undecided. A large proportion of responses were focused on anchor point '6' (36.7%), followed by point '7' (30%).

Statement 12: I think the Pharma Compounds learning tool is an important revision/learning tool

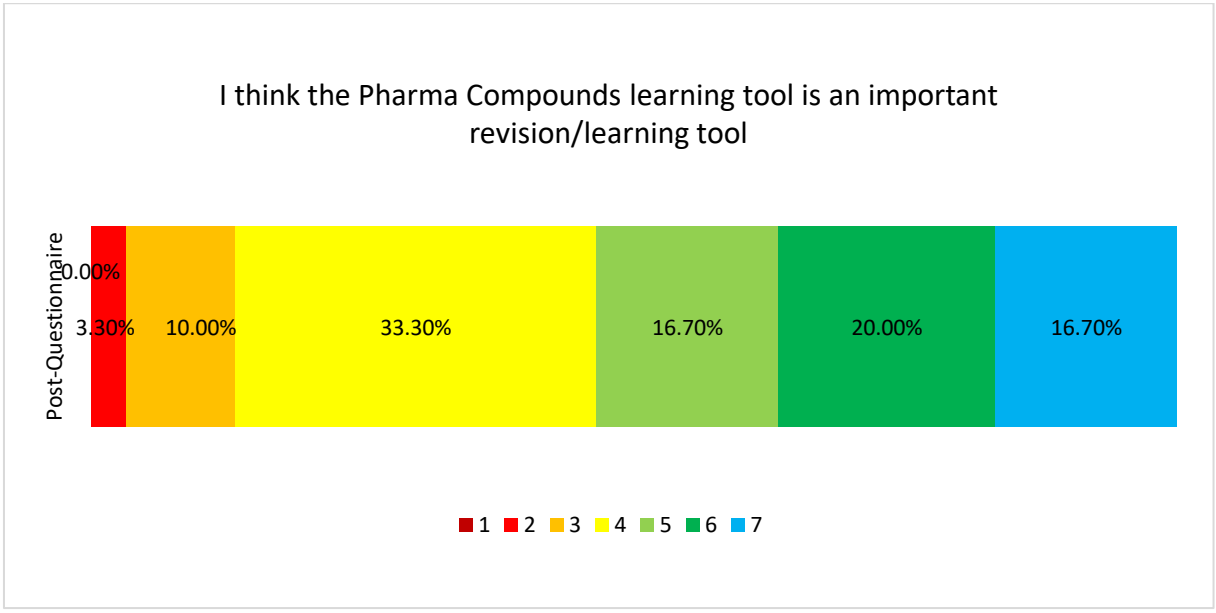


Figure 8.48 illustrates that anchor point '4' received the highest percentage of responses (33.4%). The responses are skewed towards agreement with the statement (16.7% for point '7', 20% for point '6' and 16.7% for point '5').

Statement 13: I believe using the Pharma Compounds learning tool could be beneficial to me

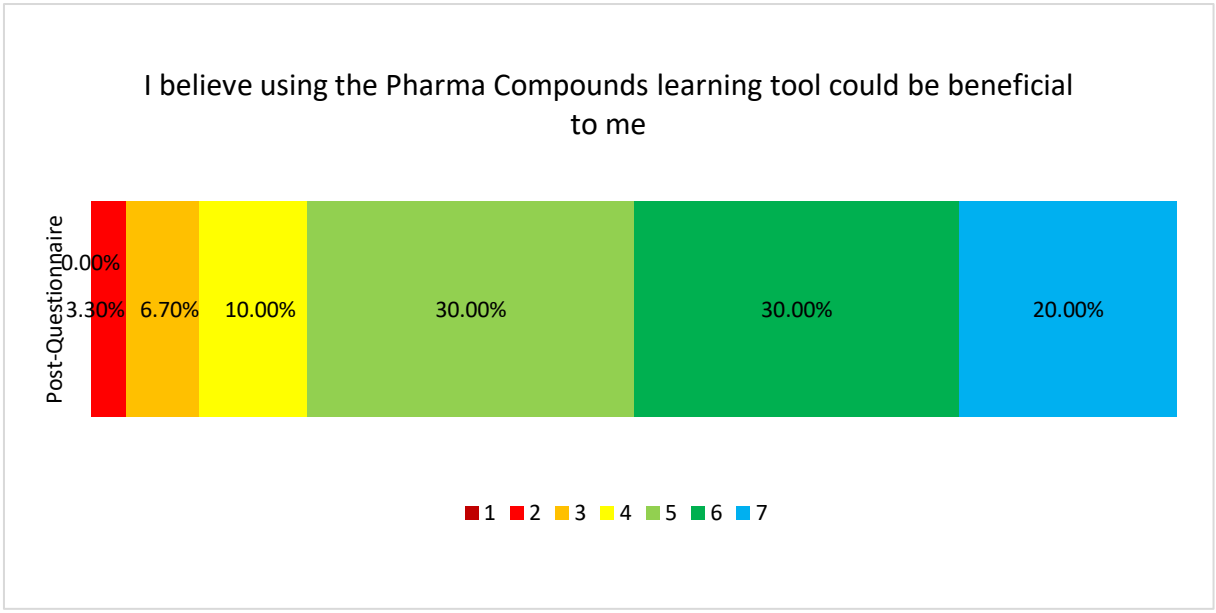


Figure 8.49 illustrates that responses to this statement were skewed toward agreement with the Likert statement. The largest proportions focused on anchor points '5' and '6' with 30% of responses each. The next largest proportion of responses was anchor point '7' (20%).

Statement 14: I would be willing to use the Pharma Compounds learning tool again because it has some value to me

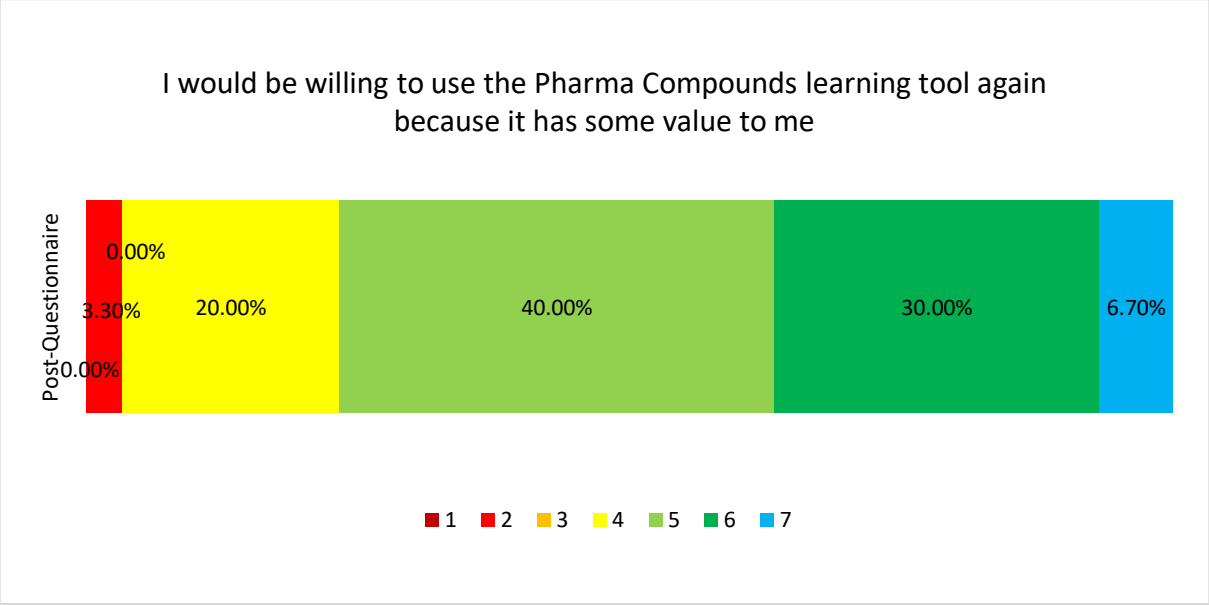


Figure 8.50 shows that the majority of responses were in agreement with the statement. 76.7% of MPharm students had some degree of agreement. Only 3.3% of participants did not agree (anchor point 2). The remaining 20% were undecided.

The overall picture presented by the result of the pre- and post-questionnaire IMI Likert statements depict that MPharm students responded with greater agreements to each of the positively worded statements that related to the use of the Pharma Compounds tool as opposed to their conventional learning methods. Conversely, a larger proportion of MPharm students responded with greater disagreements to the negatively worded IMI statements (statements 6 and 8) that related to the Pharma Compounds AR tool in comparison to their conventional learning methods. The results indicate that MPharm students found the learning tool more enjoyable to use in their learning in comparison to their conventional learning methods. It also suggests that students find the Pharma Compounds tools more useful towards their learning as opposed to their conventional learning methods as they agree the majority agree that they can easily visualise learning material.

8.5.4 Comparison of IMI Agreement Score

68 MPharm students completed and submitted their responses to the pre-questionnaire. Of the 68 participants, 30 went on to complete the post-questionnaire. The agreement scores in both questionnaires have been tabulated in appendix 45.

The results show that 67% students were in greater agreement when asked if they enjoy the use of the Pharma Cards as opposed to their enjoyment when using their conventional revision methods (IMI statement 1). 53% of students were more in agreement when asked if they had thoughts of enjoyment when using the Pharma Cards compared to their level of agreement in relation to their conventional methods (IMI statement 2). 43% of students were in greater agreement when asked if the AR educational tool could improve their knowledge compared to their level of agreement o if their conventional learning methods could improve their knowledge (IMI statement 3). 80% of participants had greater agreements in regard to the AR educational tool being very interesting compared to their level of agreements towards their conventional learning methods being very interesting (IMI statement 4). 40% were in more agreement when asked if they believe the Pharma Compounds education tool could be of some value as opposed to their agreement towards their current learning methods being of value (IMI statement 5). 47% of participants were in greater disagreement in relation to the AR tool not holding their attention as opposed to their level of disagreement with their current learning methods not holding their attention (IMI statement 6). 63% of participants were in greater agreement with the Pharma Compounds tool being fun to use compared to their level of agreement of the conventional methods being fun to use (IMI Statement 7). 86% of students were in greater disagreement when the AR educational tool was described as boring as opposed to their level of

disagreement with the conventional learning methods being described as boring (IMI statement 8). 53% of participants had higher agreement towards the AR tool being described as important as it can develop their visualisation skills as opposed their current methods developing their visualisation skills (IMI statement 9). Finally, 67% of participants had greater agreement when the AR tool was described as quite enjoyable compared to their agreement towards their conventional tool being described as quite enjoyable (IMI statement 10).

8.6 Chapter Discussion

The quantitative questionnaire findings illustrate that both sixth form and undergraduate students' self-reported intrinsic motivation towards learning improved following the introduction of the Pharma Compounds AR educational tool. The quantitative analysis showed not only statistical significance between some individual pre- and post-questionnaire Likert scale statements (Wilcoxon signed rank test) but also demonstrated statistical significance between the pre- and post-intervention IMI motivation Likert scales. Furthermore, this statistical significance was found across both sixth form and undergraduate cohorts.

Similar to the demographic data of the quiz responses (Chapters 7.2 and 7.4), over 50% of the sixth form and undergraduate participants who consented to participate dropped out at the post-intervention stage. Although expected, this fall in responses may have also been amplified due to the disruptions caused by the COVID-19 pandemic and associated social distancing practices put in place (i.e. school closures and study-from-home measures). 37.5% of sixth form students and 44.1% of undergraduate MPharm students who had

initially consented to participate completed both the pre- and post-intervention questionnaire. Although the response rates fell, each submitted questionnaire was fully completed as the Google Drive Forms documents were set to require a response for every question. This ensured that there would be sufficient data to identify any significant differences.

Following descriptive and inferential statistical analysis, sixth form and undergraduate students were in reported agreement with the use of mobile devices and the importance of technology in their education (median response of 'agree' and 'important', respectively). Both cohorts self-reported median scores of 4 (motivated) when in workshops, revision sessions, or when CGI demonstrations are used in teaching sessions. Sixth form students, however, reported median scores of 3 (neither motivated nor demotivated) when teaching in sessions resembling lectures. The same median score was reported by undergraduate students when in lectures and also in laboratory teaching sessions. Both participant cohorts reported having found the AR tool easy to use (4) and have used the tool on average between one to two times a week (1). Both sixth form and undergraduate students also reported being able to easily (4) visualise learning material after using the AR educational tool.

Both sixth form and undergraduate students reported a statistically significant increase in the mean self-reported motivation scores. On the other hand, no statistical significance was found between the means of the pre- and post-questionnaire usefulness subscales. However, students reported the AR tool to have had greater usefulness in their education than their conventional methods alone (post- vs pre-usefulness subscales). Sixth form

student's responses revealed significant differences (Wilcoxon signed-rank test) between pre- and post-questionnaires in statements; 4 (I would describe my current learning/revision methods as very interesting - I would describe the Pharma Compounds learning tool as very interesting), 7 (My current learning/revision methods are fun to use - The Pharma Compounds learning tool was fun to use), 8(R) (I think my current learning/revision methods are boring (R) - I thought the Pharma Compounds learning tool was boring (R)), and 10 (I think my current learning/revision methods are quite enjoyable - I thought the Pharma Compounds learning tool was quite enjoyable). Undergraduate student responses revealed significant differences (Wilcoxon signed-rank test) in statements 4 (I would describe my current learning/revision methods as very interesting - I would describe the Pharma Compounds learning tool as very interesting), 6(R) (My current learning/revision methods do not hold my attention at all (R) - The Pharma Compounds learning tool did not hold my attention at all (R)), 7 (My current learning/revision methods are fun to use - The Pharma Compounds learning tool was fun to use), 8(R) (I think my current learning/revision methods are boring (R) - I thought the Pharma Compounds learning tool was boring (R)), 9 (I think that it is important to use my current learning/revision methods because it can develop visualisation skills - I think that it is important to use the Pharma Compounds learning tool because it can develop my visualisation skills), and 10 (I think my current learning/revision methods are quite enjoyable - I thought the Pharma Compounds learning tool was quite enjoyable).

When comparing the mean scores of the pre- and post-questionnaire IMI Likert scales from sixth form and MPharm participants, there were slight differences and similarities. The mean sixth form participant scores on the pre-questionnaire subscales were marginally

higher than those of the MPharm participants. This indicates sixth form students had a higher degree of agreement with the statements concerning their current methods of learning/revision compared to MPharm students. The post-questionnaire IMI subscale, however, was almost identical between the two participant cohorts. This indicates that the perceived agreement to the motivation (enjoyment/interest) and the usefulness/value subscales were almost identical. When responding to statement 12 regarding the importance of the Pharma Compounds AR tool, the largest proportion of MPharm students responded by selecting anchor point 4 (somewhat agree). Sixth form students agreed at a slightly higher rate with the statement, as the largest percentage of responses had selected anchor point 5. Sixth form students disagreed with statements six and eight on both the pre- and post-questionnaire more strongly than MPharm participants. This illustrates that sixth form students felt that their current learning methods and the Pharma Compounds AR tool held their attention longer (statement 6) and were less boring (statement 8) compared to MPharm participants.

8.7 Chapter Summary

The findings from the pre- and post-questionnaire were obtained from a varied participant population. A statistically significant increase was found in both cohorts' mean self-reported intrinsic motivation towards learning after using the Pharma Compound tool compared to the self-reported intrinsic motivation towards learning before its introduction. Although the sixth form and undergraduate students reported finding the AR tool more useful towards their learning than just their conventional methods, no significant difference was found between the pre- and post-questionnaire mean usefulness IMI scores.

Together with the findings in chapter 7, these result from the quantitative element of data collected to address the aims and objectives of this research. The following two chapters (chapters 9 and 10) detail the qualitative data gathered from this study (qualitative data from the pre- and post-questionnaire and the semi-structured one-on-one interviews) before being discussed in the final chapter.

9 Year 12 and MPharm Qualitative Questionnaire

9.1 Introduction

In addition to the quantitative data gathered from pre-and post-questionnaires, qualitative questionnaire data was gathered to help fulfil the following objectives: to qualitatively assess changes in self-reported motivation towards learning; to qualitatively assess the ability of the Pharma Compounds AR tool to enhance the knowledge; to qualitatively assess the effectiveness, usefulness and useability of the Pharma Compounds AR tool in educational environments (chapter 3.2). All participants involved in this research were asked to complete a pre-questionnaire before receiving access to the Pharma Compounds intervention tool. Once the intervention period had been completed, the same participants were asked to complete a similar post-intervention questionnaire, only differing in that the intervention tool and experiences with the tool were the subject of the questions. Both questionnaires gathered quantitative and qualitative data regarding participants' views and opinions of the intervention tool and its effects on their learning process. This chapter reports the analysis of the qualitative elements of both the pre- and post-intervention questionnaires of year 12 and Stage 2 Undergraduate MPharm participants.

9.2 Sixth Form Participant Demographic Data

A total of 64 year 12 sixth form students consented to participate in completing the pre- and post-intervention questionnaires. Of these, 63 completed the pre-questionnaire, and 24 students submitted the post-questionnaire. The demographic breakdown of participating year 12 students are detailed in table 8.1 (Chapter 8).

The response rate fell from 98.4% in the pre-questionnaire to 37.5% in the post-questionnaire. 73% of pre-questionnaires were submitted by students who attended sixth form schools in Kenya; this figure fell to 37.5% in the post-questionnaire. Approximately 87% of students who completed the pre- and post-intervention questionnaire were aged 16-17, 70% were female, and just over 20% were male. 63.5% of pre-questionnaire responses were submitted by students enrolled in chemistry and biology courses. 20.6% and 15.9% of pre-questionnaire responses were submitted by students enrolled on only biology or chemistry courses, respectively. 70.8% of responses to the post-questionnaire were submitted by students enrolled in chemistry and biology courses. 12.5% and 16.7% of post-questionnaire responses were submitted by students studying a biology or chemistry course, respectively.

9.3 Undergraduate Participant Demographic Data

A total of 68 undergraduate MPharm students consented to participate in this study, and all 68 students submitted pre-questionnaire responses. 30 students then went on to complete post-questionnaires after the intervention period. The demographic data collected from MPharm student participants has been broken down in table 8.8 (chapter 8).

Approximately 70% of the completed pre- and post-intervention questionnaires were submitted by males, with the remaining responses submitted by female participants (~30%). Over 80% of pre- and post-questionnaires were completed by students aged 18-21. The larger proportion of students involved in the pre- and post-intervention questionnaires was registered as domestic students, 94.1% and 28.7%, respectively.

9.4 Qualitative Questionnaire Results

The pre- and post-questionnaires contained open-ended questions that explored participants' perspectives on research, augmented reality, likes and dislikes of the Pharma Compounds intervention tool and uses of the AR tool (during the intervention period and its use in future learning). As discussed in the Methods chapter (Chapter 5.8.1), content analysis was performed on pre- and post-questionnaire responses that resulted in seven themes. Each of which was further broken down into subthemes that can be seen in tables 9.1 and 9.2 (pre- and post-questionnaire, respectively). Content analysis of the pre-questionnaire responses resulted in the first three themes. The last five themes were formed from the analysis of post-questionnaire responses. Quotes taken from participants are included in each table as an example of codes used to form each subtheme and theme. Participant identifiers also accompany the quotes; sixth form student identifiers begin with “A” followed by a participant number, whereas undergraduate student identifiers begin with “B” followed by a participant number. Participant identifiers may have larger numbers than the number of completed questionnaires since identifiers were issued at the beginning of the study.

Pre-questionnaire themes:

- Understanding of augmented reality.
- Factors that aid motivation and learning.
- Techniques and educational tools used in revision sessions.

Post-questionnaire themes:

- Understanding of augmented reality.

- Effects on learning from using the Pharma Compounds AR intervention tool.
- Self-reported changes in motivation towards learning after use of the Pharma Compounds tool.
- Uses of the Pharma Compounds AR tool in an educational environment.
- Suggested improvements to the AR intervention tool.

9.4.1 Pre-Questionnaire Results

Theme		Number of Students		Quote	
		Sixth Form	**Undergraduate**	**Sixth Form**	**Undergraduate**
Understanding of Augmented Reality					
Examples of AR systems	Wearable	5	5	*"[A] smartphone in [a] VR headset to change [the] surroundings"* Participant A58	*"Samsung headset"* Participant B8
	Mobile devices	30	44	*"Snapchat filters"* Participant A22 *"I have used a game like Pokémon go"* Participant A64	*"PharmaCard Keele"* Participant B18 *"Snapchat on my phone"* Participant B29
	Games console	1	1	*"Nintendogs"* Participant A63	*"Yes, Nintendo 3DS"* Participant B49
Elements of virtual reality		8	8	*"Virtual experience through the use of technology"* Participant A14	*"The first thing that comes to mind when I hear augmented reality is VR"* Participant B32 *"Virtual reality and animation"* Participant B5 *"Virtual experience"* Participant B19
Combination of realities		41	14	*"This is using technology to make objects that do not exist appear to be in the same room or same space as existing objects"* Participant A2	*"The combination of the virtual world with the real-life environment in order to enhance the real-life environment"* Participant B56
Use of technology		30	20	*"The use of computers and technology to bring a 2D object to 3D and make things more visual"* Participant A22	*"The use of design and coding… to create image[s] and 3D structures that appear in the local environment of the user. This is done by using the camera of a mobile phone or any other device with a camera"* Participant B41
Altering perspectives of reality		10	19	*"A 3-dimensional technique that tricks our eyes into seeing objects on real-life surfaces"* Participant A25	*"Use of digital technology to enhance our experience in our reality"* Participant B58
Interactive environments		6	5	*"Animated objects interacting with real-life objects"* Participant A16	*"Interactive experience of a real-world environment with additional features"* Participant B22

False environment	0	6		*"Like a simulated reality or false reality"* Participant B63
Other	1	1	*"The understanding of abstracts concepts aided by technology"* Participant A37 *"Semi-real"* Participant A47	*"Use of interactive tools to assist in business/education"* Participant B50
Factors that aid motivation and learning				
Visual aids/symbolism	28	11	*"Physical demonstrations motivate me the most to learn because, I find the task or topic easier to remember and I can physically see the reasons or meaning behind the topic…"* Participant A17	*"Watching videos with interactive examples such as moving diagrams"* Participant B32
Practical/physical participation	12	7	*"The hands-on practical activities Intrigue me and stimulate my curiosity"* Participant A29	*"I usually prefer practical sessions, like the PPS [Pharmacy Practise Suit] session"* Participant B23 *"Hands-on learning rather than listening people go on and on about nothing"* Participant B15
Application of knowledge	8	11	*"Being able to put what we learn into practice which makes it much easier to understand…"* Participant A3	*"I find any method that shows the application of what I'm learning motivating as it gives me more insight into materials and makes them more interesting"* Participant B1
Didactic approach	5	8	*"Through clear tuition by a teacher at the front of the classroom"* Participant A64	*"Inspiring lecturers"* Participant B31 *"engaging lectures and then follow-up workshops"* Participant B10
Interaction between tutors and students	10	32	*"Interactive learning and occasional 1 on 1 attention because I struggle paying attention"* Participant A27	*"Workshops where learning is interactive [between students and lecturers]"* Participant B63 *"I really enjoy class demonstrations and competition created between groups"* Participant B66

Positive reinforcement	1	2	*"Textbook and notes, reading and writing them. I become motivated to do these because of my grades and trying to improve them"* Participant A28	*"I want to score as well as I can [in examinations]"* Participant B44
Comprehension	2	1	*"Textbook and notes, reading and writing them"* Participant A38	*"[writing] revision notes"* Participant B17
Other	4	4	*"Occasional 1 on 1 attention because I struggle paying attention."* Participant A28 *"It doesn't motivate me because I find I'm usually not attentive to listen, because the lectures may be very monotonous"* Participant A11 *"Reading about and learning new information in the topic"* Participant A2 *"The ability to interact at my own pace with material"* Participant A49	*"Interest in topics, deadlines motivate me"* Participant B42 *"…lectures that aren't just reading off slides"* Participant B53
Techniques and educational tools used in revision sessions				
Text bases (reading and writing)	32	31	*"I read from various resources and make notes"* Participant A43	*"Reading lecture slides, taking notes and testing myself on the slides"* Participant B2
Questions and quizzes	26	15	*"I also do topical questions to test my knowledge and make sure that I've internalised all the concepts."* Participant A43	*"Mostly questioning and answering"* Participant B63
Web/Internet bases media*	9	10	*"I mostly use the internet - websites such as YouTube and other sites specifically with AS/ A level notes"* Participant A3	*"Google drive"* Participant B41
Visual reference tools	34	47	*"Watching videos on the specific topic"* Participant A36	*"Flashcard structured learning"* Participant B41
Audio reference tools	2	3	*"Audiobooks"* Participant A32	*"Voice recordings"* Participant B50
Grouped activities	4	0	*"Consulting peers and teachers"* Participant A37	*n/a*

Table 9.1 Presents the content analysis of the pre-intervention questionnaire free text responses from sixth form (biology and chemistry) and undergraduate MPharm students. Quotes taken from participants' responses are tabulated alongside subthemes and their overarching themes. *Specifically mentioned the internet or web-based platforms.

9.4.2 Post-Questionnaire

Theme	Number of Students		Quotes	
	Sixth Form	Undergraduate	Sixth Form	Undergraduate
Understanding of Augmented Reality				
Examples of AR systems	1	1	*"It is mobile virtual reality"* Participant A4	*"Using a phone or other digital means to project or show something in 3d which is otherwise presented in 2d on a screen"* Participant B66
Interactive environment	3	7	*"This is a method of interacting with inanimate objects in the real world using advanced technology"* Participant A2	*"Interactive experience of the surrounding world (real world)"* Participant B55
Use of technology	12	10	*"the addition of digital to elements to a real-world setting using technology"* Participant A49	*"using a device to make something appear to be in the real world but is only on a screen"* Participant B26
Elements of virtual reality	4	4	*"Superimposing a computer generated image onto a computer screen surface"* Participant A62	*"Projected 3D images appear on screen when scanning a QR code"* Participant B31
Combination of realities	9	6	*"It provides a composite view of the real world through technology"* Participant A59	*"Augmented reality is the result of using technology to superimpose information — sounds, images and text — on the world we see"* Participant B41
Alternate perspective of reality	0	7	*n/a*	*"Technology which alters the parameters of what is really present and what isn't"* Participant B7
Effects on learning caused by the Pharma Compounds AR intervention tool				
Visualisation	19	22	*"Can help students visualise structures of compounds and changes in structures during reaction and help them better answer exam questions"* Participant A2	*"They are perfect for visual learners such as myself and also others who perhaps need to see something more physical in order to believe or understand concepts associated to them. In many ways, the cards really emphasise the idea of 'seeing is believing"* Participant B66
Enjoyment and engaging experience	3	11	*"They are fun to use hence tempt one to want to gain more knowledge in a new manner"* Participant A29	*"Making revision easier and enjoyable"* Participant B55
Accessibility and portability	7	4	*"Having all the information and image in the same place and easily accessible"* Participant A59	*"It is quick and easily accessible, I would find it especially useful for on the go revision as the cards were easy to keep together and most people have their phones on them at all times"* Participant B20

Theme	Number of Students		Quotes	
	Sixth Form	Undergraduate	Sixth Form	Undergraduate
			"The fact that a smart mobile phone is needed and it should be taken into consideration that some families cannot afford them for their children or rather do not advocate for them." Participant A29	*"If someone doesn't have access to a phone/tablet"* Participant B44
Use of mobile device	2	3	*"it requires technology which could become a distraction in my studying"* Participant A50	*"The main disadvantage is that obviously also using your phone for this could mean students were more prone to distractions e.g. replying to texts, social media etc"* Participant B20
Educational content	9	12	*"there are only a limited amount of molecules available"* Participant A53	*"The limited amount of variation of the cards, i.e. more cards with more content"* Participant B32
Understanding and recall of concepts	7	9	*"It has made it easier to apply knowledge to compounds"* Participant A61	*"Using the cards in many ways has enhanced my confidence, perhaps because I am able to make a point and then go back to the appropriate card and just check or use the projection as a means of clarification and use it to follow my thought process"* Participant B66
Study Techniques/ experience	4	8	*"It improved my studying techniques by visualising the molecules"* Participant A25	*"It gave me an idea to make flashcards for some of my lectures"* Participant B3
Interactive learning	0	9	*n/a*	*"I found it extremely easy to resort to the cards because I could interact with the compound being"* Participant B66
No changes reported	5	17	*"it hasn't really changed anything"* Participant A51	*"I haven't used it much to know how it had impacted my learning process. I wanted to use it but there wasn't much that I could use it for"* Participant B35
Learning system failed or stopped working	6	3	*"Sometimes doesn't always work"* Participant A62	*They are difficult to get it working. The app seems too simple and have no option to ask for help. It also shows different chemical structure/ concept than what the card says"* Participant B6
Learning system functionality	4	10	*"If I lose the cards I lose use of the app"* Participant A57	*"Carrying the cards with you, it would be nice to have one plain card and download different compounds"* Participant B39

Theme	Number of Students		Quotes	
	Sixth Form	Undergraduate	Sixth Form	Undergraduate
Self-reported changes in motivation towards learning caused by the Pharma Compounds tool				
Increase motivation due to engaging the learner	6	6	*"It allows me to engage more with my learning. So I therefore look forwards to revision sessions"* Participant A56	*"It's made me view learning as something that can be implemented with new types of innovative technology"* Participant B68
General increase in motivation	9	7	*"Positively, I would be more driven to revise when using the cards"* Participant A24	*"It can be said that my motivation has been increased when using the cards and for that reason I really would love to see the idea going further and perhaps becoming specific to degrees and again to particular topics"* Participant B66
No change in motivation	6	12	*"it stayed there same as I'm quite easily motivated"* Participant A50	*"My motivation hasn't changed towards learning because of the learning tool as I couldn't use it much"* Participant B35
Increased motivation due to visual elements of educational tool	0	2	*n/a*	*"Wanting to learn more things visually"* Participant B23
Uses of the Pharma Compounds AR tool in an educational environment				
Reference/Revision tool	9	12	*"[Use] alongside written theory"* Participant A58	*"I think it would be useful to be issued with cards that were subject specific after or at the start of lectures when starting a new topic/module that we could use for our own learning"* Participant B20
Demonstrations (chemical reactions and anatomy)	2	5	*"I would like for it to be used when taking about 3d structures of molecules"* Participant A8	*"More frequently, especially during physical chemistry and pharmacodynamics/ kinetics sessions"* Participant B7 *"It should be applied when we look at information that involves pictures or imagery. For example, learning about the anatomical system of the body or looking at therapeutics"* Participant B41
Collaborative learning sessions	6	2	*"Class discussions and interactive sessions"* Participant A57	*"in workshops or as part of an activity"* Participant B26
Additional areas of the course	3	6	*"When learning about different groups of compounds"* Participant A54	*"Someone should make these cards for all the related subjects in pharmacy"* Participant B3

Theme	Number of Students		Quotes	
	Sixth Form	Undergraduate	Sixth Form	Undergraduate
Quizzes	1	1	*"To allow question and answer quizzes that really put your memory to the test according to what it has just taught you"* Participant A29	*"Used to test knowledge"* Participant B5
Suggested improvements to the AR intervention tool				
Range of educational content	15	15	*"Expand the subjects that this method of learning can be applied to"* Participant A25	*"broader range of topics or more specific to the topics that we are learning"* Participant B26
Increased and improved functionality	3	4	*"Develop how molecules interact with each other, for example hydrolysis or condensation reaction"* Participant A58	*"Don't use cards, select a molecule and have the molecule appear on any surface like a hand or table"* Participant B63
Fix system bugs	3	2	*"Just make the software of a better standard"* Participant A64 "*it still does not work on my phone. The screen is blank whenever I try using my camera."* Participant A8	*"Improve the app better so it doesn't flicker when the object is on… The app needs to work with the cards successfully every time so that users keep using the app and the cards"* Participant B6
Quizzes	2	1	*"by adding revision questions to the different compounds associated with exam boards so that the experience is more efficient when close to exams"* Participant A63	*"Making it more interactive. Perhaps a quiz to test what we remember"* Participant B23
More detail information to accompany 3D models	1	2	*"It could perhaps explain the compound shown on the display"* Participant A1	*"I liked the Pharma Compounds learning tool a lot, one thing I did notice that might help was when there was the option to flip between different screens e.g. with the cell division card and the e/z isomers card - specifically on the e/z isomers card it might be helpful having text on screen when the isomer changed from a cis or trans isomer"* Participant B20

Table 9.2 Presents the content analysis of the free text responses of sixth form (biology and chemistry) and undergraduate MPharm students who made comments relevant to the subthemes found in the post-intervention questionnaire.

Both sixth form and MPharm participants were able to provide examples of AR systems they have either used or witnessed, the most frequently reported were mobile based AR systems. Both groups of participants were able to collectively provide descriptions and or definitions of AR. Sixth form students most commonly reported that AR systems combined realities and used technology to do so. MPharm participants also most commonly reported AR systems use technology and provide an alternative perspective on reality. The understanding of AR environments was maintained as both groups of students reported the same features that would be found in AR systems during the post-questionnaire. Sixth form students most frequently reported that they find the use of visual aids/symbolisms as a key factor that aids motivation and learning, whereas the interaction between tutors and students was the most commonly reported feature of learning that aid motivation and learning in MPharm students. The themes of techniques and educational tool used in revision sessions revealed that for both sixth form and MPharm participants, visual reference tools, text-based methods and questions/quizzes were by far the most frequently reported techniques and tools used during revision sessions.

In the post-questionnaire, when questioned about the Pharma Compounds effect on learning, MPharm and sixth form students most frequently reported on the visualisation elements that related to the links between concepts visual representations. Both groups of participants frequently commented on the educational content of the tool referring to the limited range of topics. Some students, mostly MPharm students reported the AR tool had no reported change in their learning. This became apparent in the responses relating to changes in motivation, as no change in motivation was most frequently reported by MPharm students. Sixth form students on the other hand most frequently reported a

perceived general improvement in their motivation. Both groups of participants believed that the AR educational tool could be used in a number of scenarios but most frequently would be used as a reference/revision tool. In relation to comments that referred to potential improvements to the AR educational tool, both participant groups most frequently reported changes focussing on the range and complexity of the educational content.

9.5 Chapter Discussion

The qualitative data collected from the open-ended pre- and post-questionnaires contributed to meeting the objectives of; appraising the effectiveness and usefulness of the educational tool as well as comparing the perceived changes in knowledge and intrinsic motivation towards learning after using the Pharma Compounds AR tool. The qualitative questionnaire findings illustrate that participants reported understanding the intention and role of the Pharma Compounds AR tool in their education and could see its value with the current educational content included in the app. However, students also expressed that the value of the educational tool may be improved should the educational content include more specialised and nuanced material.

Before delving into the open-ended questions on both pre- and post-intervention questionnaires, participants were asked to define what they believed the term “augmented reality” to be. When looking specifically at the pre-questionnaire responses, a large proportion of participants provided comments that suggested ‘augmented reality’ involved combined realities, a changed perspective of reality and that required technology. In addition, many responses highlighted that mobile devices were the most commonly encountered pieces of hardware used to view AR. The responses to the same open-ended

question in the post-questionnaire indicated that participants' understanding of the term 'augmented reality' remained the same. Comments received in the post-questionnaire included definitions encompassing 'use of technology', 'combination of realities' and 'interactive environment'. Caudell and Mizell (1992) first coined the term 'augmented reality' to describe a technology that can augment a user's visual field with the use of heads-up display technology. Other renditions of a definition have been suggested as the technology developed, such as the definition given by Azuma (1997), which focuses on the combination of realities – AR supplements reality by superimposing virtual objects over the real world. These findings suggest that participants had a very good understanding of what kind of technology augmented reality is and the capabilities of an AR system. Observations made by other researchers could explain this finding - AR's ability to establish innovative and enjoyable interactions as well as engage consumers with brands, relates to its relevancy as a successful feature of marketing campaigns, expanding possibilities for both consumers and brands, particularly in the entertainment industry (Calder *et al.*, 2009; Javornik, 2014; Shankar *et al.*, 2010). It should also be noted that a significant proportion of responses specifically included mobile devices when providing examples of an augmented reality system. This may have resulted from the rise in mobile devices that encompass or have augmented reality functionality (Martin *et al.*, 2011; Mekni and Lemieux, 2014; Yim *et al.*, 2017).

The use and inclusion of visual tools and resources used in teaching sessions were reported as being extremely popular among both sixth form and undergraduate students who participated in this study. Comments most frequently included the use of visual aids and symbolisms such as flashcards and YouTube videos. Visual learning methods have been

known to aid problem-solving scenarios and understanding concepts, encourage new ways of thinking, communication, and enhance education and practices within science and engineering (Ainsworth, 2006; McGrath and Brown, 2005). It is common for several different visual references and tools to be used in STEM environments, with their use encouraged by educational practice guides (National Research Council and Geographical Sciences Committee, 2005). Different visual representations can provide complimentary perspectives to an abstract concept, potentially resulting in a much deeper understanding should a learner be able to integrate multiple visual representations into a single model (Ainsworth, 2006; Cox and Brna, 2016; Schnotz, 2005; Wu *et al.*, 2019). Comments associated with improved visualisation of concepts and education content were extremely frequent when participants were asked questions about the Pharma Compounds AR education tool. When questioned about how the intervention tool affected individual and group study sessions, a large proportion of respondents reported that their ability to visualise concepts and molecular structures had improved. Wu *et al.*, (2013) listed 'visualising the invisible' as an affordance of AR in their 2013 review. Many other authors and researchers reported similar findings; AR learning systems can help learners visualise abstract concepts and unobservable phenomena such as airflow and magnetic fields, chemical compounds and structures (Arvanitis *et al.*, 2009; Clark *et al.*, 2011; Dunleavy *et al.*, 2009; Fjeld and Voegtli, 2002; Wu *et al.*, 2013). As stated, educators encourage the combined use of different educational tools that improve the visualisation capabilities of learners and, therefore, would imply that the use of the Pharma Compounds tool should also be encouraged. With comments from the sixth form and undergraduate students that related to the perceived improvement in their visualisation skills and motivation, as well as

comments that highlight the popularity of visual learning methods, it can be said that the AR Pharma Compound system may improve the users' visualisation of educational concepts.

A proportion of participants noted interactions between tutors and students and the use of visual aids and symbolisms, such as moving diagrams, mind maps and online videos, as particular aspects of teaching sessions that can improve motivation towards learning. The interaction and nature of the dialogue between tutors and students have long been a focal point of interest (Mercer and Dawes, 2014). Dialogic teaching is a purposeful teaching method that uses dialogue to aid learners' development and understanding (García-Carrión *et al.*, 2020). This teaching style would therefore seem to be removed from the conventional didactic teacher-student question and answer dynamic and more positioned towards maximising teacher-student interactions through dialogue between the two parties to attain the best possible educational outcomes, as mentioned in chapter 1.6 (García-Carrión *et al.*, 2020; Norris and Coutas, 2014). However, the findings indicate that both groups of students favour various teaching approaches, from the more conventional didactic approaches to methods that rely heavily on interactive educational tools.

Sixth form and undergraduate students reported favouring educational environments and educational tools that required the application of knowledge. They reported that applying their knowledge to real-world scenarios places their learning into context, thus making the material easier to digest. Subsequently, students commented that contextualised material improved their motivation to acquire more knowledge. Concerning the Pharma Compounds AR tool, undergraduate and sixth form students reported that the educational tool made their revision experience easier and more enjoyable, "tempting" them to want to learn

more. Comments were received that detailed how students perceived the Pharma Compounds tool had improved their ability to understand and correctly and confidently recall concepts. Their confidence was said to have stemmed from the ability to quickly check the 3D representations to affirm their understanding. In addition to ways the tool had already impacted learners' perceived knowledge, students also suggested that the inclusion or incorporation of quizzes and the pharma compounds tool would provide learners with further opportunities to test their knowledge and improve their learning experience (Kornell and Son, 2009).

Following on from perceived changes in knowledge, comments were also received that related to perceived changes in motivation in both the pre- and post-questionnaire. As shown in table 8.3 and discussed above, students reported that using visual and interactive tools, and teaching scenarios that focus on applying knowledge, contribute to improved motivation towards academic endeavours. This quality can also be associated with the Pharma Compounds AR tool. As a visual and interactive educational tool, several participants reported an increase in perceived motivation towards their learning and attributed that increase to either the visual or interactive components of the Pharma Compounds AR tool. Additionally, some participants reported having experienced a general improvement in their motivation towards studying. The comments from participants suggest that using the Pharm Compounds AR tool may improve learners' perceived intrinsic motivation towards learning when using the intervention tool compared to their reported motivation before its use. Researchers have also come to similar findings, detailing that using augmented reality educational tools contributes to learners having higher levels of motivation towards learning (Sotiriou and Bogner, 2008). Nevertheless, it should also be

mentioned that some participants reported no perceived improvement in their motivation towards learning.

Participants were given the opportunity to comment on the ideal uses of the Pharma Compounds AR tool. The majority of comments received related to using the intervention tool as a reference source during classroom and revision sessions. Students reported that they would like to use the tool during teaching sessions as a source of additional information when covering related concepts and phenomena. Comments were also received advocating for its use in tutor demonstrations, specifically when exploring chemical reactions and anatomical structures. Additionally, a proportion of students reported wanting this educational tool included in collaborative learning sessions where it can be used to initiate discussions or as part of workshop activities. In addition to preferable uses of the AR tool, participants also stated that more content would make it more usable.

As with any technology, the Pharma Compounds AR educational tool can be improved. Participants were given the opportunity to provide feedback detailing what they did not find useful and elements they would like to see included or improved. As mentioned above and shown in table 9.2, the overwhelming majority of comments received related to the range of educational content available in the current system. Sixth form students who shared such comments noted that they would have liked to have seen content that not only focused on molecular biology and chemical structures but also on other topics they would encounter during their course, with a particular emphasis on a wide range of functional groups and their activity. Undergraduate MPharm students, on the other hand, were interested in topics that specifically related to nuanced aspects of the MPharm course and physical

anatomy. Participants suggested the inclusion of content that would help explain pathophysiology and the mechanism of action of the medication. The programming of the Pharma Compound system could allow for these topics to be incorporated, providing a three-dimensional model of the phenomenon exists or can be animated from scratch. As stated in the intervention tool design chapter, elements of sixth form chemistry and biology courses and undergraduate MPharm courses were taken and implemented into the Pharma Compounds educational tool. Unfortunately, due to the limited development time, the more complex and detailed content could not be completed in time to be included in the release of the AR system (chapter 6.9.2). There is, however, enormous potential for more complex and detailed content to be incorporated into the AR tool going forward.

Other than the limited content of the educational tool, the other most frequently received negative comments about the stability of the app's software. Participants reported on several occasions that they were presented with a blank screen and could not progress to the educational content, or their camera was not working as it should have. Additional comments reported that the 3D models would flicker, disappear, and reappear as if the device's camera partially recognised the target image. Although students experienced these shortcomings, they still reported benefits from using the educational tool or commented on potential benefits should these issues be remedied (11.4.3).

All undergraduate students who completed the post-questionnaire also completed the pre-questionnaire (100%). For sixth form students, 23 out of the 24 who had completed and submitted the post-questionnaire had initially completed the pre-questionnaire (95.8%). Participants were primarily required to complete and submit the pre-questionnaire to

receive the intervention tool and therefore continue onto the additional stages of this research. This proposed sequence of stages was, however, disrupted by the COVID-19 pandemic, and as a result, the response rates fell after the intervention period. Therefore, undergraduate and sixth form students who may not have completed and submitted the pre-questionnaire were sent the intervention tool and asked to complete the post-questionnaire. Although these participants did not submit pre-questionnaires, their perspectives on the AR tool were still considered useful. All post-intervention questionnaires contributed to the response rates in tables 9.1 and 9.2. Both pre- and post-questionnaires were designed so that all questions were compulsory to answer before being submitted to gather as much data as possible from participants. Upon review of both questionnaire responses, the majority of questions were answered appropriately. However, on very few occasions, participants entered 'n/a' or a passage of text that did not relate to the question being asked. Doing this allowed them to submit the questionnaire without providing a valid response.

9.6 Chapter Summary

The qualitative findings from the pre- and post-questionnaires were gathered from a sample of participants that varied demographically. Participants expressed their opinions on their learning methods and habits both before and after the introduction of the Pharma Compounds AR educational tool. Participants provided their perspectives on what they believed AR to be before and after the intervention. They also reported particular factors of their learning that improved their perceived motivation, such as using visual aids, application of knowledge, and dialogue/interaction between themselves, tutors, and their peers. Before commenting on their opinions of the Pharma Compounds tool, participants

reported what techniques and educational tools they find effective and currently employ – visual reference tools such as flashcards and diagrams, web-based resources such as YouTube, text-based exercises like quizzes, as well as group activities. Comments were received that detailed how the Pharma Compound tool improved the perceived visualisation skills of learners and brought a greater sense of enjoyment to their learning experience. The educational tool was said to have provided learners with a new learning experience that eased the learning process and recall of concepts. Participants reported improved motivation towards learning due to the Pharma Compounds AR tool engaging learning and providing visual representation. Participants also commented on the AR tool that they believed would improve their experience, such as a broader range of educational content, improved functionality with quizzes and interactivity with the onscreen 3D models.

The results from this chapter form part of the qualitative data collection in this piece of research. The following chapter presents the results from the video call interviews (chapter 9) before being discussed and triangulated with the findings from this chapter and the quantitative data gathered in chapters six and seven.

10 Interview Results

10.1 Introduction

Video call interviews were conducted to further understand students' and tutors' views and perspectives towards the Pharma Compounds AR educational tool and its implementation. This chapter reports on and discusses comments made by interviewees on the use and implementation of the AR educational tool. Section 10.2 details the demographic data of interview participants, followed by the categories uncovered from thematic analysis. Section 10.3 details the themes relating to perspectives on educational teaching methods and students' resulting confidence. Section 10.4 reports on the themes relating to motivation, followed by the themes relating to perspectives on the Pharma Compound AR tool in section 10.5. Section 10.6 reports on themes relating to participants' perspectives on the educational content of educational tools. Section 10.7 details the themes relating to the uses and application of the Pharma Compound AR tool. The themes relating to participant perspectives on improving the Pharma Compounds AR educational tool are reported in section 10.9, followed by themes that detail perspectives on the tool's implementation in educational settings in section 10.10. The discussion of the interview results can be found in section 10.11, followed by the chapter summary in section 10.12.

10.2 Participant Demographic

Sixth form biology and chemistry students and undergraduate MPharm students who had used the Pharma Compounds AR educational tool during the intervention period were invited to participate in one-on-one interviews. The initial response rates for the interviews were low, and as a result, recruitment was extended to include the tutors of students who were involved in previous elements of the study and tutors who teach the same subjects at

the same education level in the same institutions. As mentioned in Methods section 5.5, a proportion of tutors had no experience using the educational tool - therefore, participants who were unaware of the educational tool's capabilities were given access to the educational tool, informed of the purpose of the study, and what they would be asked to do.

A total of eleven participants consented and participated in the video call interviews; their demographic data and participant code can be found below in table 10.1. Each interview lasted approximately 45 minutes in duration. Four participants were students – one sixth form student from Kenya and three undergraduate MPharm domestic students. The remaining six participants were tutors of sixth form and undergraduate MPharm students – one sixth form tutor from the UK and five undergraduate MPharm tutors.

Participant Identifier	Participant Type	Level of Education	Country	Gender
A2	Student	Sixth Form	Kenya	Female
T1	Tutor	Sixth Form	UK	Female
B63	Student	MPharm	UK	Male
B9	Student	MPharm	UK	Female
B68	Student	MPharm	UK	Male
T2	Tutor	MPharm	UK	Female
T3	Tutor	MPharm	UK	Male
T4	Tutor	MPharm	UK	Female
T5	Tutor	MPharm	UK	Female
T6	Tutor	MPharm	UK	Male
T7	Tutor	MPharm	UK	Male

Table 10.1 displays the demographic data of students and tutors who participated in the video call interviews. Participant identifiers beginning with "A" denote sixth form students, "B" denotes undergraduate students, and "T" denotes tutors. The identifiers were assigned upon initial consent to participate.

After conducting framework analysis on the video call interviews, eight major categories emerged from the transcripts of both student and tutor interviews. Those eight categories

are listed below, and the themes within those categories are detailed in sections 10.3 to 10.10:

- Perspectives on educational teaching methods and students' resulting confidence.
- Perspectives on students' motivation towards learning.
- Perspectives on the Pharma Compounds AR educational tool.
- Perspectives on the educational content of the Pharma Compounds AR educational tool.
- Uses and application of the Pharma Compounds AR educational tool.
- Perspectives of similar educational tools.
- Perspectives on improvements to the Pharma Compounds AR educational tool.
- Perspectives on the implementation of the Pharma Compounds AR educational tool into educational settings.

10.3 Perspectives on educational teaching methods and students' resulting confidence

Comments made by participants on educational teaching methods and the confidence they instil in students are presented below. Participants were first asked general questions that pertained to students' preferred styles of learning, which led to the identification of two themes. First, the varied types of teaching sessions experienced and the associated perception of learners (section 9.3.1), and second, confidence in the new knowledge learners would have acquired in those types of sessions (section 9.3.2).

10.3.1 Types of teaching sessions and the associated perception of learners

The initial theme identified from the interviews focused on the different types of teaching sessions learners experienced and their mood (tutors' perception of students' moods) while

in these sessions. Student participants had already detailed the different teaching sessions they had experienced when completing the pre-questionnaire earlier in the study. However, in the interviews, participants reported what teaching sessions and aspects of learning they found most enjoyable compared to others. Regarding tutor participants, they reported on what they perceived students enjoyed. Most participants reported on three main areas - application of knowledge, learner-to-learner and learner-to-tutor discourse, and the use of technology/visual tools.

Eight interview participants, across sixth form and undergraduate teaching, reported a preference for learning activities that revolved around the application of knowledge and considered these scenarios enjoyable.

> *"I particularly liked the workshops and how you'd go through questions and answers [between students and the sessional leads], anything that pretty much encouraged active learning because I can't really learn passively just writing notes down after, I prefer to answer questions on it and things like that to help me stick it in my own mind basically…"* [Participant B63, MPharm student]

One participant highlighted the specific relationship between the connection and application of newly acquired knowledge in other areas of their courses and real-world scenarios.

> *"I get a lot of second years say, oh I'm enjoying the course much more because it relates more to pharmacy… when you can show [students] where it fits in with*

other bits of their teaching, where it fits in with assessments, where it fits in with real life [they enjoy it]" [Participant T5, MPharm Tutor]

Five participants, all involved in MPharm education, reported that students might find teaching sessions that revolve around discourse, either between students themselves or between students and tutors, to be more enjoyable and beneficial to their learning than those which are more didactic in nature.

"I'd go with from my experience and comments that have been made informally… but they [students] really enjoy the tutorial-type environment where they can discuss with their peers, and I think the tutorials really work in the model of a sort of flipped classroom… I think it encourages more discussion around tasks we've given them beforehand, and it sort of provokes more of a challenge." [Participant T2, MPharm Tutor]

A further five participants, sixth form and MPharm, reported that the use of technology and visual learning aids contributed to more enjoyable learning environments.

"They do enjoy technology enhanced sessions but the technology's got to have some benefit for them. They can't see the point in just using technology for technology's sake, it's got to be – it's got to enhance it somehow… if it's a case of say the 3-D cinema they're able to see molecules a lot more easily and get their head round those kinds of things." [Participant T5 MPharm Tutor]

Additional comments made by participants included topics that focussed on using innovative technology and creating authentic learning scenarios with appropriate functionality to real-world scenarios and practice.

> *"I think they do like innovative things and I think giving them options is always good and sort of promotes a more inclusive curriculum"* [Participant T2 MPharm Tutor]

> *"if we're going back to authenticity, we want things to be authentic. So you want your interface to be as authentic as possible"* [Participant T4, MPharm Tutor]

Comments were also received related to aspects of teaching sessions that participants believed were not as conducive to their learning as initially intended. Although participants detailed their fondness for dialogue between students and their tutors, many comments expressed discontent with elements of current learning environments, mainly the didactic approach of lectures. Four participants reported on the practicality of lectures but also reported that these sessions may not engage learners as much as others.

> *"Even with interactive lectures, which I know [some tutors have] done an awful lot on with the clickers and so on and so forth, I'm still not entirely sure how much active learning they do. It's a very passive learning method…"* [Participant T4 MPharm Tutor]

Two MPharm tutors reported that the examination style may have negatively impacted their students' learning process. These reports mainly revolved around multiple-choice question examination formats.

> *"…[MCQs] they don't test anything apart from your ability to either spot wrong answers or just get lucky... that's why having an MCQ exam for the registration assessment is fundamentally flawed."* [Participant T4, MPharm Tutor]

One participant further explained the problems with MCQ exams and reported more appropriate ways a student's knowledge and competency could be measured and simultaneously correct the learning process.

> *"a lot of us would argue that actually the only way to measure competence is through a competency-based exam which is like CBAs (competency-based assessments) or an OSCE (objective structured clinical examination) because then you can see, have they got the skills, and equally so have they got the knowledge?... the GPhC even say, it's (registration exam) not a knowledge exam it's an application of knowledge and it's a competency exam. But then you cannot measure competency through an MCQ."* [Participant T6, MPharm Tutor]

10.3.2 Confidence in knowledge

Participants' thoughts concerning confidence associated with students' learning were explored. Three MPharm tutors reported that they perceived students felt as if they lacked

confidence in their own knowledge. This was possibly caused by the belief that their knowledge was not at the level they believed it should be.

> *"What I think they see as confidence is probably, they want to see themselves as a pharmacist being confident, but they're not quite there yet so they don't feel they're confident. Whereas actually, at the level they are they are probably more confident than they think"* [Participant T2, MPharm Tutor]

Another participant reported comments of a similar nature that also went on to expand on the previous quote. They offered a potential reason why students may experience this lack of confidence in their own knowledge and ability where it may originate.

> *"Confidence in lectures and learning situations comes in because students don't ask questions, pharmacy students don't ask questions... we [Tutors] don't know what you don't know if you don't tell us what you don't know… and it's that lack of confidence in admitting lack of knowledge that is a real barrier, which I don't think younger students possess… there is that dissonance there. But even at the start of the year when I spend an hour telling them, 'We're expecting you at this level to have a baseline knowledge of zero', we are teaching you stuff that you have never seen before, we don't expect you to know it. So, when we ask a question, 'Do you understand it?' we're fully expecting you to say, 'No, not completely' or 'No, not at all' or 'Yes, only partially'."* [Participant T4, MPharm Tutor]

In relation to students' comments about confidence in the knowledge they had acquired, two participants, both MPharm students, reported their confidence improved after they received feedback, be that from peers, tutors, or assessments.

> *"I'm pretty confident with that [question and answer workshops with tutors], it got me fairly decent grades last year because of that type of learning so, yeah, I'm really confident with that type of learning."* [Participant B63, MPharm Student]

One tutor offered a potential explanation as to why feedback helped students to build confidence in newly acquired knowledge.

> *"Students appreciate more interactive sessions and rapid feedback so that they can judge their position if you like within the class, or within the knowledge that they've got."* [Participant T3, MPharm Tutor]

10.4 Perspectives on motivation towards learning

Comments and perspectives on students' motivation towards learning are presented in the sections below. Participants were asked to comment on learners' motivation towards learning, which resulted in the formation of the following themes: section 10.4.1 details comments regarding sources of motivation, section 10.4.2 relates to changes in the sources of motivation and if/when these changes may occur. The final section, 10.4.3, details comments associated with motivational factors created due to using AR educational tools.

10.4.1 Sources of motivation towards learning

Five of the eleven interview participants reported career prospects or progression as a main source of motivation for students: one sixth form student, one MPharm student, one sixth form tutor and two MPharm tutors.

> *"I really wanted to leave high school and get to the next stage of my life. So, that was a big motivation for me to study, so that I wouldn't have to repeat the same year again."* [Participant A2, Sixth Form Student]

Another popular source of motivation reported by participants stemmed from assessments and the drive to achieve better scores or grades.

> *"I try to be better at something if I wasn't good at it before or trying to improve my grades so, try and get like 1% better than last time"* [Participant B9, MPharm student]

> *"Students these days are very much, you know, focussed upon the granular marks that they can accrue at each stage as it goes through."* [Participant T3, MPharm Tutor]

Tying into the notion of assessment as a critical motivational factor towards learning, one participant added the concept of 'fear of failure' as an additional factor.

"I can have like a career path, I can think in the future but if I don't pass an exam, then what's the point like, it's just going to be a big like alteration, like what am I going to do?... If I'm going to be real, it's the fact I don't want to fail." [Participant B68, MPharm Student]

On the other hand, there were also reports from participants that a major source of students' motivation towards learning originated from the desire to acquire knowledge and a genuine interest in the subject topics.

"I like science kind of things; I like understanding the body… the MPharm [course] is structured so that encourages me to learn it as well because I do find it interesting." [Participant B63, MPharm Student]

"Some of them are absolutely fascinated in the science or the geography or the language whatever they're doing, and they want to understand it more and they're interested in it, and some of them have a real passion for other subjects to learn it at that higher level." [Participant T1, Sixth Form Tutor]

10.4.2 Changes in motivation towards learning

When questioned if the source of a learner's motivation would change, both students and tutors reported that assessments and the need to improve one's grades will always be a leading motivational factor regardless of the scenario. However, two participants, both MPharm tutors, also recognised and reported the need to change the fixation surrounding assessment grades and marks to trigger a change in students' motivation to learn.

"I don't think so, no like I think everybody wants to get better grades [laughs] so, yeah, I don't know. I don't know what else would change that mmm yeah, I don't know actually." [Participant B9, MPharm student]

"I don't think you can change the fixation on marks, I don't think you can change assessment backwash. What you have to do is change the assessments. So, you make the assessments real life, as authentic as you possibly can so that you are truly assessing for learning so that whilst the student is going all out to pass that assessment, they are actually learning while they do it." [Participant T4, MPharm Tutor]

Participants reported that a potential change in the main source of motivation towards learning might occur when an individual recognises they must learn to perform effectively. In the case of pharmacy students, they must learn to practice effectively as healthcare professionals.

"I guess it's being good at what you do, then again, cause if you're not going to continually learn more what your profession is about, I guess what do you call it, you fall out of the loop and you don't deliver the best patient care, I guess like helping people, you're going to be less good at helping people." [Participant B63, MPharm Student]

"I would say there's a change; I don't say it's a blanket [change] because you've got people on either end of that scale. You've got some who merely want to get through the course, scrape through, get the qualification, earn money, whatever. You do have a number of students who are motivated at the start because – and again, it's that self-motivation that comes back, it's "I'm interested in it, I want to do it, I want to learn, I'm interested in diseases, I want to know how kidneys, lungs, livers work. Why do drugs interact? What is it that makes them interact?" So, you've got some students who have that motivation…" [Participant T6, MPharm Tutor]

10.4.3 Motivation created from the use of the AR educational tool

Seven participants, including students and tutors, reported that using the Pharma Compounds AR educational tool would and did have a positive effect on students' motivation towards their academic studies.

"Yes, I think it would [also] increase my motivation in other subjects" [Participant A2, Sixth Form Student]

"I think if AR was properly implemented like in the way it was done [with the Pharma Compounds AR system], I think it would have an effect cause you think like, wow like, its cutting edge technology incorporated into your learning, it could be a boost, they're pushing the technology, they're trying to help us learn, we just like give the same energy back and just like try and use it as much as we can if you know what I mean…" [Participant B68, MPharm Student]

Two tutors reported how creating a relevant need for using such technology in education would improve students' drive towards learning.

> *"If we as lecturers and teachers can emphasise that [the reason behind using the technology] I think it will build their motivation to learn some of these really difficult concepts because it does stimulate a sort of enthusiasm."* [Participant T5, MPharm Tutor]

10.5 Perspectives on the Pharma Compounds AR tool

Interview participants were asked about their initial general thoughts and opinions on the Pharma Compounds AR educational tool. Further exploration of their responses led to the themes detailed below. Section 10.5.1 details the range of comments received that related to the value the educational tool provided, and section 10.5.2 focuses on comments that related to the functionality and useability of the AR tool.

10.5.1 Educational value

One sixth form and four MPharm tutor participants provided comments that pertained to the AR tool improving users' understanding and comprehension of the subject material.

> *"I think it really helped them with the understanding of that [Biological molecules] and as that's the backbone to many, many topics I think then they're having a solid understanding there at a molecular level really aided*

understanding of other things that were more complex later." [Participant T1, Sixth Form Tutor]

"I certainly think it definitely benefited some students as an option and helped them to develop their understanding." [Participant T2, MPharm Tutor]

Another notable theme of comments received detailed the perceived usefulness and value participants attributed to the educational tool.

"Initial thoughts were it's, it's very good, well-constructed… particular aspects I could see how I could use it within my own teaching… you've got to choose the right elements. That's not a panacea for everything but I could see by choosing the right element when you're teaching it would very, very useful." [Participant T3, MPharm Tutor]

All participants reported that the Pharma Compounds AR educational tool's main affordance was visualising learning material.

"I'm able to visualise it, I thought it would be easier for me to be able to remember like which parts come together, which one's form" [Participant A2, Sixth Form Student]

"I think that would be really useful in visualising it because I remember a lot of students struggling to visualise that kind of thing. So, I think that would be really very helpful" [Participant B63, MPharm Student]

"I think especially for the students who found the concept more difficult, they used it more so, if they couldn't cos some people can see a 2D structure and visualise in their heads and erm I think for people who needed that it made them, they used it a lot more to get their head around it if they couldn't do it themselves." [Participant T1, Sixth Form tutor]

"I can see that being extremely useful because they've got something they can twist and turn through the three dimensions and then come up with the answers." [Participant T4, MPharm Tutor]

10.5.2 Functionality and Useability

Participants frequently commented on the in-app functionality of the educational tool. The most commonly reported perspectives are related to the 3D visual functions of the educational tool. Six interviewees, both sixth form and MPharm tutors and students, shared comments containing this subject matter.

"It was great for the 3D structures… I think it brings it to life. I think it makes it more interesting, I think it's learning in a different way so, thinking at it from a memory point of view it lays down neuro pathways, other neuro pathways to the same memory which means that you remember it better of course and the more

examples that you have to link to that memory is good so, I think it gives them [students] another element, a way of learning which may suit certain children's learning style better especially if they're like a kinaesthetic learner or something like that, that practical seeing of it might help and lay down firmer foundations to memory I think." [Participant T1, Sixth Form Tutor]

The second most frequently reported comments referred to the mobile app's combined useability and physical interactivity. These comments were all shared by five tutor participants.

"The second thing is looking at the value of what you get and what I liked was the actual structure and how you could manipulate the structure. And the thing where you can interact the two [cards] together. I think that was quite good, you know I had various thoughts on that in terms of things like you could build that into drugs stability." [Participant T7, MPharm Tutor]

In addition to these comments that were in favour of the tool's functionality, participants also expressed some drawbacks and limitations. Five participants, both sixth form and MPharm students and their tutors, reported comments that detailed shortfalls of the AR systems functionality.

"It [the app] actually stopped working after a while on Android. I'm not sure about Apple iOS but I think it also stopped working but it stayed for a bit longer on iOS than on Android." [Participant A2, Sixth Form student]

"If I could just use an app and like erm I don't know just like point my phone screen at somewhere and then like get the picture to load and then do it like that yeah so, without the cards that would be really good." [Participant B9, MPharm Student]

Two participants (MPharm tutors) expressed potential issues that could arise should this type of system be integrated as a core feature in an academic setting. The limitations centred on access to the technology and the cost associated with its use.

"So the cost of the people producing the graphics, producing the cards, producing the – being able to tie the thing up, downloading it to the erm – producing the app that then downloads... but you know, it's like when you're going to these schools and you're showing it to schools, are the schools willing to then say, 'Well we would actually invest some money in this' or 'We would buy a set of cards." [Participant T6, MPharm Tutor]

"The one issue I have with access...in terms of that erm, you're looking at demographics and whether people can afford technology or not?" [Participant T7, MPharm Tutor]

10.6 Perspectives on the educational content of educational tools

Comments on the educational content of the Pharma Compound AR educational tool and the requirements to formulate educational content into a successful educational system

were received and led to the creation of the themes below. Section 10.6.1 details comments made regarding the development of the educational content for augmented reality educational tools and section 10.6.2 details comments about AR being an appropriate method to deliver educational content.

10.6.1 Development of educational content for use in AR educational tools

Two tutor participants stressed the importance of a collaborative process when developing material to be imported into a educational tool. Emphasis was placed on having students and tutors involved in constructing the educational content.

> *"The key thing is to seek feedback from students. Erm, you know maybe using analogy about film directors and actors and how they may interpret things differently… I think it starts with the person creating the thing but then it develops and grows into what each individual makes it. It becomes a sort of partnership I suppose it doesn't become your app or my teaching resource or whatever it might be, it becomes the thing the student uses, and you work with them to do that."* [Participant T7, MPharm Tutor]

Additionally, reports were made detailing the vast and varied material elements, particularly in MPharm education, that would need to be covered and the process by which this could be done.

> *"I think it's very difficult to do that on a multidisciplinary programme. I think you've got to break down the programme, and this is where maybe modular*

approach might be [better], you know, you've got to look at that. But the ideal would be to have a stream of sessions when you've got underpinning material, more applications of it build up, start to introduce any augmented reality, er, tools, to get to a point where you're confident that students have been able to see what it is from 2-D into 3-D" [Participant T3, MPharm Tutor]

This same participant went on and further reported the following concerning the disruption caused by the COVID-19 pandemic.

"The situation that we're in at the moment with the, er, providing online learning during the COVID, er, pandemic is really I think where some of these answers sort of lie in. You know, we've got to re-develop all our teaching for delivery and online and offline, er, scenarios. So, you know, if I'm standing up and giving a lecture, you know, a physical, face to face, physically present in situ lecture, I've still got to provide an electronic resource which gives the students the same experience. In terms of where we're at, you know, I'm looking at this from a redesign, I've still got to get this material across but from a redesigned point of view. And so, er, having this, er, facility, being able to sit down with you and say, this is what I need to deliver, this is what I've done in the past, or this is what I need to build up to and say, right this is what I need to deliver. This is how I think I can deliver these bits; can you identify or assist me with this." [Participant T3, MPharm Tutor]

10.6.2 AR as a valid method to deliver educational content

Participants provided comments that revolved around the effectiveness of the Pharma Compounds AR educational tool as a viable method to deliver educational content to learners. Five MPharm tutors reported how the intervention tool would contribute to and form part of a blended learning approach supporting existing teaching methods.

> *"So, I think again it would form part of that blended learning approach, so it's something else, it's an additional opportunity for the student to aid their learning for revision or however they want to use it best. I certainly think it would definitely benefit some students as an option and help them to develop their understanding."* [Participant T2, MPharm Tutor]

One participant, an MPharm tutor, explained how the utility of the educational tool determined its viability to deliver educational content and, in turn, its application within group-style teaching sessions.

> *"Utility is always the important thing in this, and it's not just, oh that looks nice and shiny, it actually does something and for me this was. When I'm using it by myself, obviously that's not the case but when you look and think what can you do with it, you can maybe do it as a small group thing, you could maybe do it as something that improves interaction with students amongst themselves so they can then teamwork more appropriately."* [Participant T7, MPharm Tutor]

One participant (MPharm tutor) reported the need for learning environments that help bridge the gap between simulation and real-world experiences.

> *"It's that continuum between no experience and lots of experience that people sit on. It's the expert's novice journey essentially, but if you want to move somebody from novice to expert, they have to learn to have confidence in their own abilities...I think a tool like this could be very, very useful to take students on that journey from novice to expert by forcing them to make decisions."*
>
> [Participant T4, MPharm Tutor]

10.7 Uses and application of the Pharma Compound AR tool

The interviews also explored how participants incorporated or may incorporate the augmented reality educational tool into their learning/teaching practices. Comments provided by participants that relate to the theoretical and ideal uses of the Pharma Compound AR educational tool are explored in section 10.7.1. Section 10.7.2 contains reported comments on the actual uses of the educational tool during the intervention period. Finally, section 10.7.3 explores the comments made by participants that relate to the utility of the educational tool.

10.7.1 Theoretical/Ideal use of the educational tool

Upon being introduced to the intervention tool, five participants (one sixth form student, one MPharm student and two MPharm tutors) reported they would most likely use the tool as it was designed to be used.

"I think personally I would use your tool to deliver underpinning knowledge that didn't require, er, calculation or it wasn't testing anything, it was, er, an assisted technology to learning. For those students who are interested in the end game or the output or whatever, this would help them get the better marks and to be able to understand the material." [Participant T3, MPharm Tutor]

"I think when I was first learning about certain reactions in biology and chemistry, I thought it would fit in… [I thought] it would help me to see exactly how those molecules come together. And because I'd be able to visualise it, I thought it would be easier for me to be able to remember like which parts come together, which one's form and all that." [Participant A2, Sixth Form Student]

Five interview participants (one sixth form student, one sixth form tutor, one MPharm student and two MPharm tutors) reported comments that suggested the functionality of the educational tool affords itself to be used in a wide range of age groups –from kindergarten/reception (age four to six) to undergraduate education.

"I guess the basic – you know, the basic flashcard would say apple… In words and you say, 'Right, what does that say?', 'A-P-P-L-E, apple', 'Right, there's an apple'. And you've kind of got that already in 3D." [Participant T6, MPharm Tutor]

"These cards would have really helped when I was in year 10, year 11, when I was first like learning proper chemistry." [Participant A2, Sixth Form Student]

Comments from two interview participants (MPharm student and MPharm tutor) reported that the intervention tool would have been ideal for displaying anatomical diagrams and models to further aid learning and understanding of course content.

> *"I guess going over the renal components at the moment. Erm, where they're showing like the diagrams of the nephrons and stuff like that. I guess it makes it a lot more interesting if it was in that format."* [Participant B63, MPharm Student]

> *"…you start then getting into the realms of where else you could use it in the course, anatomy… 3D anatomy would be fantastic wouldn't it? To actually be able to go and see a 3D kidney and to actually see – and you've got me now, the loop of Henle and the urethra."* [Participant T6, MPharm Tutor]

In addition to comments made regarding anatomical models, participants also reported that the integration of more complex chemical models and reactions would have made the intervention tool more aligned with the perceived needs of learners.

> *"I'm sure in an interactions way that's probably the best that I can think of closest to this that it might work well for I think, through drug-interactions and things like that, yeah. Drug interactions Used in sessions that cover interactions between drug molecules - chemical functional groups interacting with one another."* [Participant T2, MPharm Tutor]

One participant reported the potential use of the Pharma Compounds AR tool in an educational game.

> *"You could come up with [a game], 'Right, of these drugs how many have three, four chiral centres? How many have four oxygens? How many have a benzene ring? How many have a nitrate group?', so sort them into those. So, you could use it in different place at different times, which is you know, 'How many of the following is likely to have a pKa of less than…' whatever."* [Participant T6, MPharm Tutor]

10.7.2 Actual use of the educational tool

Of the five interview participants who used the educational tool during the intervention period, four participants used the Pharma Compounds app as it was designed to be used.

> *"The way I went about it was like, say I'm starting a subject like, I'm starting just from the beginning, I'm trying to revise it, I'd redo the lecture slides like try get an overview of it and then I'd used the cards to like to try and, for that initial stage of like learning it if you know what I mean. And I'm not getting all the details, but I can see the cards can help you on like stuff you can miss, if you know what I mean"* [Participant B68, MPharm Student]

Two participants reported having either changed their use of the educational tool or used it differently than initially anticipated.

"When I first used the cards, it was fine, but I didn't really have an opportunity to use them that much because they just showed like the physical reactions, the way that the molecules come together but a lot of the work depends on the notes and the information that you can get from the notes, I didn't have an opportunity to use the cards that much." [Participant A2, Sixth Form Student]

"I could just use them like simply as like flash cards cos it's got like little pictures on them" [Participant B9, MPharm Student]

10.7.3 Perspectives on the utility of the Pharma Compounds AR educational tool

As discussions surrounding the use of the Pharma Compounds AR educational tool progressed, participants expressed particular areas of teaching where this technology may thrive. These comments related to the phases of learning in which the tool could be used – the introduction of new concepts, the consolidation of concepts in the main phase of the learning process, and finally, the revision phase. Seven of the eleven interviewees (one sixth form student, one sixth form tutor, two MPharm students and three MPharm tutors) reported that the Pharma Compound AR educational tool would be a valuable instrument to introduce brand-new topics to learners.

"you can introduce it using the cards and get them to have a little look at a molecule and you go, 'And what do you think that is?' and, 'Can you see any differences between that molecule and this molecule? Where would you see it?' [Participant T1, Sixth Form Tutor]

"That's the best way the cards helped us like, in that initial stage when you're learning about it like from when you have like no prior knowledge and then you're jumping in." [Participant B68, MPharm Student]

"I can see the value in using it, to deliver material about models and molecules at lower levels of stereo chemistry." [Participant T3, MPharm Tutor]

Eight participants (one sixth form student, one sixth form tutor, one MPharm student and five MPharm tutors) also highlighted that using the intervention tool could be highly beneficial during the bulk of students learning to help consolidate one's knowledge of the subject matter.

"…later when you're consolidating it you can make them really look at the position of like the hydrogen or hydroxyl groups and use that actually when you're teaching it when you're really using the concept and that sort of thing." [Participant T1, Sixth Form Tutor]

"I certainly think it would definitely benefit some students as an option and help them to develop their understanding. Like I said, sometimes it might just be to support the underpinning knowledge" [Participant T2, MPharm Tutor]

"when I come back to your app, it's something you could use as a platform to sort of develop interactive learning, small group learning… I could be here with a

couple of other people, we could be sharing this screen, we could be sharing our views on this, it was something that built up a very positive image of potential" [Participant T7, MPharm Tutor]

Nine participants (one sixth form student, one sixth form tutor, one MPharm student and six MPharm tutors) reported that students could find a use for the educational tool when revising learning material.

"I know they used them a lot when they were revising, they used them at home just to consolidate understanding." [Participant T1, Sixth form Tutor]

"yeah it's like, sometimes [I could] refer to this, like when I want to just remind myself of it, I guess it could be used there for certain diagrams." [Participant B63, MPharm Student]

"… even just a case of, er, the revision, er, so actually after the class students are going through their notes, going back over afterwards, okay I don't quite understand this concept. So, you can scan your card or scan the picture on the KLE or whatever. And actually, you're able to, er then be able to, er, think okay so I didn't quite get it in class, but now I can see it and I can think about it and yeah take time." [Participant T5, MPharm Tutor]

Six participants (sixth form and MPharm students and tutors) reported that the Pharma Compound AR educational tool could be incorporated in all three stages of learning – introduction of a topic, consolidating knowledge of the topic and revision of the topic.

> "I think when you're introducing a new topic, especially in A level, because it's a big jump from the way you learnt it in GCSE. I think then it would be good, like the teacher would say you can put out your cards, and it would be good for visualising basically" [Participant A2, Sixth form Student]

10.8 Perspectives on similar educational tools

As participants expressed their opinions on the intervention AR educational tool, they also shared their experiences and opinions on similar augmented/virtual reality devices that they may have seen or used in the past. Seven of eleven interview participants, all at the MPharm level, had used or experienced augmented or virtual reality environments at their current institution for either teaching or learning.

> *"…we're in that theatre quite a lot but we don't actually use the 3D stuff. 3D stuff's usually with like Carolyn's stuff or erm like Alan sometimes erm so, maybe like two or three a semester, two or three lectures a semester maybe."*
> [Participant B9, MPharm Student]

> *"I think an example I would use in the School of Pharmacy is the 3D stuff Alan does, now if you think about that, that looks great but a lot of guys are now saying to us, what's the point, you know it looks wow but what's the value, the*

value the other guys will then say, you can clearly see the interaction of the drug and the receptor so it helps to look at that in terms of the 3D and the sort of interaction of the two. Now, what I mean by all that is from my point of view, the technology's fine if it has an application." [Participant T7, MPharm Tutor]

As the last quote highlighted, participants reported positive experiences when using AR/VR systems so long as they had an application towards learning. This was the case for all other participants who had reported having used a VR/AR learning system.

"It [Digital Health Hub] pointed out like the different parts that were significant, I can't remember exactly what the topics were now like, but I remember doing that and I think it was helpful for like digest the information." [Participant B63, MPharm Student]

10.9 Perspectives on Improving the Pharma Compounds AR educational tool

Ten of the eleven interviewed participants reported several ways the educational tool may be improved. Many of the comments received related to improving the functionality of the app. This category supported the first element of the Normalisation Progression Theory (NPT), further discussed in section 10.11. Five participants, sixth form and undergraduate students and tutors, expressed the need to improve the 3D animations that would help present the specific phenomena or concept of the card in more detail.

"I think bringing them together to see the reactions to actually see the reactions and how it actually happens and where the bonds, so they don't just snap

together so like how it comes together and where the bonds form… I think that sort of thing because that takes it to the next level of our learning, our teaching them, that would be really helpful, and I think that would help them."

[Participant T1, Sixth Form Tutor].

Comments that related to the inclusion of sound and audio elements were received by five interview participants (one sixth form student and four MPharm tutors). All of which explained how an audio explanation of the onscreen 3D animations would be highly beneficial, particularly for students and learners who may be visually impaired.

"I think that would help and maybe some narration about what's happening, why those specific molecules are coming together, I think that would help a lot."

[Participant A2, Sixth Form Student]

Three participants repeatedly expressed comments related to the educational tool's gamification. These reports included the inclusion of interactive quizzes as well as individual and group game formats.

"I guess really you could almost link it to kind of quiz type thing as well where you will get peers to do things, activities and compare scores. Yeah, that might give a bit of motivation as well thinking about it" [Participant T2, MPharm Tutor]

There were reports from two interviewees to alter the format of the augmented reality system. The Pharma Compound AR educational tool is an image-based AR system, and

comments received suggested the removal of the target image and have the 3D models generated without the need for the system to recognise target images.

> *"Do the cards have to be there necessarily?... maybe something like without the cards maybe just like an app or something yeah, something like that cos like everyone has a phone on them so, you know it's easier than taking cards with you and then like there's a thing of like losing it as well so if you lose the cards, you can't really use it."* [Participant B63, MPharm Student]

10.10 Perspectives on the Implementation of the Pharma Compounds AR educational tool into educational settings (NPT framework)

Throughout the interviews, participants were asked questions about the implementation of the Pharma Compounds AR educational tool. The questions were adapted from the Normalisation Process Theory framework to understand how users of the intervention tool would implement the AR educational tool into everyday use (Chapter 5.7.3). The comments received were organised into four main themes that overlap with the four domains of the framework:

- Distinguishing the tool and identifying its purpose (coherence).
- Value of the educational tool and the assessment of it being worthwhile (collective action).
- Support for the educational tool to ensure its success (cognitive participation).
- Participants buying into the idea of this new novel educational tool (reflexive monitoring).

All eleven participants provided comments that demonstrated they could differentiate the intervention tool from other available educational tools and correctly identified the intended use and function of the educational tool.

> *"What you've got is this sticking ball models of molecules, [Molymod®] that's the one, yeah, we had those at school and they're great because it's something, you know its tactile and you can look at them and you think, oh now I understand chirality because you've made the thing the same way but differently. The app does the same thing, but it does it for a different generation that's more use to technology so my era it was those models, those sticking ball models, and they're fun to make, you know but is really engaging, the previous generation had Lego, so it's the same sort of, it's almost an advance onto that."* [Participant T7, MPharm Tutor]

> *"What's really nice is to be able to manoeuvre them around and look at them like in a 3D model rather than a 2D shape cos that's what it's normally drawn on your work sheets and they usually see it flat like that"* [Participant T1, Sixth Form Tutor]

Of all the participants interviewed, ten provided comments that reported some agreement with the inclusion of the educational tool in their work. They explained the value the educational tool held or would hold in a student's education.

"From a student's point of view, 'This is what they'd like' and that strikes me as being very much of erm, 'This is what I'd like to do at home, to do my learning at home' and then becomes a revision tool" [Participant T4, MPharm Tutor]

"I think there's still a lot of potential there in like, how you could definitely teach that, especially with A-level classes because I remember going, learning the different bond angles and trigonal planar, tetrahedral all that kind of stuff." [Participant B63, MPharm Student]

Along with reporting the value the educational tool was perceived to have held, participants also provided comments that explored their personal assessments of the tool being worthwhile.

"This is a really quick tool rather than you having to build it all and then that takes a long time to build a Molymod® you know, whereas you can flick on your phone with the cards to like alpha glucose, beta glucose, it's really quick and it helps their understanding quickly rather than spending ages building Molymods® which is not what you want them [students] to do." [Participant T1, Sixth Form Tutor]

The third group of comments reported by participants related to the support required for the Pharma Compounds AR system to be a successful educational tool. Support within the NPT framework does not relate to the support students need to use the intervention but rather what support an intervention requires to be successfully integrated into everyday

educational environments. Nine of the eleven interview participants provided comments that discussed support from key shareholders that would make a system like this successful.

> *"The teacher would say you can put out your cards, and it would be good for visualising basically and it can be peak your interest in it [subject material]"* [Participant A2, Sixth Form Student]

> *"But they have to have it in school, they have to have it in lessons as part of their, er, you know Smart Star thing, like how many stripes are shown on your side in pencil, where's your iPad. So, you know, as soon as all of this becomes the norm coming through, we have to do it."* [Participant T3, MPharm Tutor]

> *"Yeah basically. You know, er, as it becomes, er, the norm, you know, for example high school or sixth form college or wherever, you know, if this was embedded as part of the teaching that you get. We always complain about students have been taught the answer to the exam and forget everything else, you know. But er, you know, my kids have used interactive whiteboards at primary school and now it's the accepted norm. And my son he started high school last week and they're all given iPads and they have to bring it to every lesson because everything that they're taught, and they do have a lot of interactive stuff on the iPad."* [Participant T3, MPharm Tutor]

The final grouping of comments received pertained to participants buying into the idea of the novel intervention tool. Five interviewees commented on familiarity with mobile technology, and that mobile technology might be a useful adjunctive learning instrument.

> *"Kids today use their phones and videos and things a lot more, this is linking into the technology that they actually learn from nowadays whereas moly mods are how we learnt because we didn't have or I learnt anyway I'm older than you how we learnt it's kind of like erm we didn't have the tools that we have but there's so much that can be learnt through virtual learning and that is, I think that's how they, that's the medium they work in more."* [Participant T1, Sixth Form Tutor]

10.11 Chapter Discussion

A wide range of comments received from sixth- and undergraduate students and tutors detailed perspectives on the novel Pharma Compounds AR educational tool. Participants also provided comments related to their more well-established teaching and learning practices. Comments received throughout the interview contributed to the four elements of the Normalisation Process Theory (NPT) framework.

Beginning with comments made towards different styles of teaching sessions participants had experienced, there were a large proportion of participants whose comments aligned with questionnaire responses. Sixth form and undergraduate students and their tutors reported scenarios where; newly acquired knowledge was applied; there were opportunities for discourse between peers and educators; and practical participation contributed to enjoyable learning environments. These factors also came into play

concerning the Pharma Compounds AR tool. Students reported how the AR tool provided them with an opportunity to apply their newly acquired knowledge, and with further improvement to the app, such as the inclusion of quizzes, that opportunity could be extended. In relation to discourse between peers and educators, one MPharm tutor commented on the ability of the Pharma Compounds AR tool to encourage such dialogue, stating that they could imagine themselves viewing 3D models along with students while they all share their views on the subject matter. The similarities in these comments with reports made in the literature of what may contribute to enjoyable learning environments would indicate that the AR tool would also contribute to enjoyable learning environments.

Additionally, interview responses indicated that visual aids and symbolisms in teaching sessions could contribute to enjoyable learning environments. This notion was again reported concerning the Pharma Compounds AR educational tool. Both student and tutor interviewees repeatedly reported that the intervention tool helped improve students' ability to visualise and perceive concepts and phenomena. Undergraduate and sixth form students reported the same affordance in the post-intervention questionnaire. As Dunleavy *et al.*, explained (2009), augmented reality learning systems possess a unique affordance in that they allow for the visualisation of otherwise invisible phenomena and provide a means for learners to correct their misunderstanding of concepts and phenomena (Liu *et al.*, 2009; Sotiriou and Bogner, 2008). With this understanding, it could be said that using the Pharma Compounds AR educational tool may improve the visualisation of concepts, potentially contributing to a better understanding or a correction of misinformed understandings of phenomena.

Comments provided by both student and tutor interview participants detailed the idea of motivation before and after using the intervention tool. Several responses from student participants highlighted that many learners have been, and continue to be, driven by the need to achieve a better assessment score or grade. This idea was also echoed in the perspectives of tutors. From their experience, they believed students were focused primarily on the granular marks and what was required to pass or achieve a better assessment grade. The nature of academic assessments seems to place emphasis on the need to pass rather than learn and understand the material. One tutor further explained that there was a need to amend the style of examinations and assessments to mimic real-life scenarios to shift the focus from granular marks towards learning and understanding principles and concepts. Types of assessments, MCQs in particular, may restrict students' progression towards the top of Miller's triangle (from the Knows stage) and Bloom's taxonomy (from the Knowledge/remembering stage) (Anderson *et al.*, 2001; Bloom *et al.*, 1956; Miller, 1990). At these stages, learners focus on remembering material instead of understanding the phenomena to explain why it occurs (Witheridge *et al.*, 2019). Shifting towards more authentic assessments and examinations, learners will need to not only recall concepts but also understand and apply their knowledge, thus encouraging progression higher up on either Miller's triangle or Bloom's taxonomy. Tied into the driving force behind achieving better scores, one participant highlighted that the fear of failing an assessment also contributed to wanting to achieve better grades. Other sources of motivation were reported from interviewees, such as students having a genuine interest in the subject material and the acquisition of knowledge, progression, and career prospects, as well as the ability to perform effectively as a professional.

Participants also expressed their thoughts on whether the main source of motivation for learners would change and, if that change occurred, at what point. Several interviewees recognised that if learners are required to pass examinations and assessments, a significant source of motivation towards learning will come from the pursuit of better granular marks. As mentioned above, this source of motivation may be unavoidable unless the assessment style changes. Several participants commented that a change in the main source of motivation might occur when the learners recognise the importance of what they are learning rather than focusing on retention for an assessment. The ability to perform the role of a professional pharmacist is a long-term goal for many MPharm students; however, some are 'blinded' by the short-term objective of passing an assessment to progress to the next stage of their studies. It is well known that the understanding of material should be emphasised over the memorisation of facts (National Research Council, 2000). The National Research Council (2000) further explained that although facts are important for thinking and problem-solving, usable knowledge is not the same as a list of disconnected facts and that expert knowledge is connected, organised and contextualised. Therefore, it is improbable that learners will reach an expert level by learning to memorise facts. However, should they shift their focus towards understanding the subject material, they would have a better chance of obtaining and maintaining expert knowledge. This may be easier for students whose biggest motivational drive towards learning is centred around acquiring new knowledge, having a genuine interest in the topics, or wanting to perform the role as a professional effectively.

Concerning the Pharma Compounds AR tool, Students reported that the novel educational tool improved their perceived motivation towards learning. Tutors' comments indicated

that they also perceived that learners' motivation and interest towards learning had improved. Comments from some participants indicate that the improvement in motivation may stem from students' interest in the medium from which the educational material is presented. The Pharma Compounds tool utilises smartphones, a familiar and popular tool, to access educational content in a novel way. The blend of familiarity and practicality of the device, and the novelty in the presentation of educational content, seem to generate learners' motivation towards learning.

A theme from the interviews was the educational content and the development of quality educational tools. Two participants highlighted the need to include both student and tutor shareholders in the design and development stages, further supporting the process by which the Pharma Compounds AR tool was developed (Chapter 6). Feedback on the educational content and functional capabilities of a educational tool is incredibly valuable to understand the needs and wants of the consumers (Chew *et al.*, 2018). The perspectives of educational tutors can form a powerful tool in the development of educational tools – they can provide unique insight into particular subject areas students seem to have difficulty learning, they recognise what areas of education need to be improved and ultimately, what they would like to achieve in their learning environments (Vanderlinde and van Braak, 2011). Critical to the success of a educational tool, developers must also consider the learner and develop an engaging system (Chew *et al.*, 2018). This becomes particularly important when you consider smartphones. An engaging smartphone educational tool helps to hold the learner's attention and reduce the chances of them becoming distracted and using other mobile applications such as social media (Chapter 9.5, table 9.4).

On several occasions throughout the interviews, participants commented on the utility of the AR educational tool. Participants reported they felt the Pharma Compound tools could be integrated into three different stages of the learning process: introduction, consolidation, and revision of topic areas. Tutors also stressed the importance of the educational tool to have appropriate utility within the scope of their teaching methods such that it is seen as a core element of education rather than a 'nice to have' element of the course. Chew *et al.*, (2018) explained that focus should be placed on the use or potential use of the technology rather than the technology itself. These comments from the literature again support the development process of the Pharma Compounds AR educational tool, as both students and tutors were consulted regarding its content and functionality.

As mentioned in the methods chapter (chapter 5.8.3) and earlier sections of this chapter (section 10.10), NPT was used to develop the interview guide (Appendix 44). The framework identifies factors that promote and inhibit the routine incorporation of a complex intervention into everyday practices (Murray *et al.*, 2010). Focus is placed on the work individuals and groups do to normalise the use of an intervention tool. The framework has four main components: coherence, cognitive participation, collective action, and reflexive monitoring. The components, however, are not linear but share a dynamic relationship with one another and the broader context of the intervention (Murray *et al.*, 2010).

The Pharma Compound AR educational tool had a high degree of "coherence" within the NPT framework as all participants could easily distinguish the intervention tool from other more established educational tools. A few comparisons were made that linked the Pharma Compounds AR system to Molymods®, however, interviewees understood the mobile

intervention tool had greater utility and a more comprehensive application for use in different teaching sessions with different themed content. The concept of utility was further explored as participants commented on their potential and actual uses of the educational tool and possible ideal uses for the system. As mentioned in section 10.7, some interviewees reportedly used the educational tool more conventionally (scanning the cards and using the 3D models as a visual reference during teaching/revision sessions). In contrast, some found other less obvious ways to incorporate the educational tool into their practices, such as using the physical cards as 'flashcards' and not using the app to generate 3D representations. Concerning ideal uses of the educational tool, comments were made about including more complex content, i.e., more complex chemical reactions and anatomical structures. There were reports and comments related to the gamification of the Pharma Compounds educational tool. Gamification can be defined as "using game-based mechanics, aesthetics and game thinking to engage users, motivate action and promote learning and solve problems skills" (Kapp, 2012). The gamification of educational tools has been popular, especially with the use of AR (Ayer *et al.*, 2016; Calle-Bustos *et al.*, 2017; Chen *et al.*, 2015; Liu *et al.*, 2016). The reported theoretical and actual ways the tool was used contributed to establishing degrees of "cognitive participation" and "collective action" concerning the NPT framework. As all interview participants were able to explain several ways the current intervention tool could and would be used (section 9.7), the AR app can therefore be associated with a high level of "cognitive participation". However, the level of collective action was not as high as the other framework elements, as only a small number of students and tutors interviewed had used the Pharma Compounds educational tool during the intervention period. The remaining tutors who were interviewed did not have an opportunity to use the educational tool in their teaching, however, they stressed that they

would be willing and would encourage its use and the use of similar devices providing the educational content applied. Five of the eleven interview participants provided comments that fell into the “reflexive monitoring” category of the NPT framework and related to comments of positive feedback that referred to the application of the educational tool and the potential benefits it could bring to the more visual learners.

The main aim of this research was to evaluate the effectiveness of the Pharma Compounds AR system as an educational tool for undergraduate MPharm and sixth form biology and chemistry students. To improve the intervention tool's effectiveness as an educational tool, interview participants were asked to provide comments about the issues and limitations they experienced when using the AR system. Comparing the volume of positively and negatively phrased comments, a small proportion highlighted the limitations and shortfalls of the educational tool. The most frequently reported limitations are related to the functionality and useability of the tool. More specifically, comments suggested that the target image cards be removed entirely and that the 3D models are pre-loaded on the mobile device. The Pharma Compound AR system is image-based and requires the recognition of a unique target to generate the associated 3D model (Martín-Gutiérrez *et al.*, 2010). The removal of the target images would require the educational tool to either be a location-based markerless system requiring an internet or GPS connection or a markerless system with the 3D molecules pre-saved onto the device and an in-app menu to select the required 3D model the user wishes to view (Maryam Abdinejad *et al.*, 2021; Edwards-Stewart *et al.*, 2016). A markerless system would, however, see a popular function removed – when two different target images are placed together, thus forming a third target image, will generate a completely different 3D model – an aspect which both student and tutor

participants reported to enjoy and have great potential to expand upon for other areas of learning. The only other limitations reported by interview participants related to cost and access to the technology should a educational tool like this be intergraded into everyday educational use. The cost and availability of AR systems may have contributed to participants' reports regarding previous use of an AR system in an educational environment. Only MPharm students and tutors had reported experiencing similar educational tools, whereas no reports were received from sixth form students and tutors. A potential factor may be that the funds and recourses available to educators and learners are much greater in university education; therefore, more extravagant tools may not be available to sixth forms and college students. An additional limitation that may have impacted the responses of MPharm participants, mainly tutors, is that the Pharma Compounds AR tool was developed at Keele University and based on the Pharma Card Keele mobile app, which has been used as a demonstrations tool during University Open Days. Therefore, previous exposure and familiarity with the original tool may have impacted their perception of the Pharma Compounds AR tool.

A potential limitation of the video call interviews was the sample size. A greater number of undergraduate tutors participated than other participant groups (undergraduate students, sixth form tutors and sixth form students). This distribution of participants may have shifted the data towards the views of MPharm tutors. Nevertheless, the limited perspectives shared by other participant groups provided valuable insight. The broad theme surrounding visualisation and the role of visual tools in the learning process was considered to have reached saturation as no new perspectives surrounding the theme emerged from the additional interviews (chapter 5.4.2). Nevertheless, it is important to note that although

saturation may have been reached from 11 participants, conducting further interviews may have resulted in new perspectives on the theme of visualisation. As mentioned in Methods chapter 5.4.2, data saturation can be difficult to determine. The inclusion of an additional interview could result in a new theme; conversely, it is possible to reach saturation by conducting detailed interviews from a small sample.

The decision to conduct video call interviews was discussed in the methodology chapter (Chapter 4.5.3); therefore, the success of the data collection method will be discussed here. The choice to conduct video call interviews over in-person interviews was heavily influenced by the COVID-19 pandemic and the social distancing measure brought in place to reduce the spread of the virus. As the methodology chapter detailed, focus groups were initially proposed to generate rich and varied data that would contribute towards triangulation with data collected from other data collection tools (Bertrand *et al.*, 1992; Fielding, 2012). However, the effect of the pandemic contributed to reduced response rates and participation in the post-intervention elements of this research, and as a result, one-on-one interviews were conducted, replacing focus groups. Consequently, participants relative inexperience with platforms such as Microsoft Teams and Zoom meant that conducting video call sessions with multiple members would have added a layer of difficulty.

Video call interviews were preferred over telephone interviews due to the importance of visual cues from participants. Visual cues are important when attempting to build and develop rapport and read body language. Irvine *et al.*, (2013) explained that building good rapport and reading body language is critical to acquiring rich qualitative data sets. All

interviews were scheduled at the earliest convenience of the participants to ensure they would be comfortable and have plenty of time to share their thoughts. An advantage of semi-structured interviews over structured interviews is that they can be led by the interviewee's responses and guided by the interview protocol. For instance, when asked about the sources of motivation towards learning, one student seemed slightly reserved in their initial response. The interviewer then changed the wording of the question to work around the interviewee's apprehension to provide an answer – personal and everyday life connotations were used to phrase the question so that the interview participant felt like they were speaking for themselves rather than on behalf of a collective (Eckert, 2020), e.g. “what changes to elements of your education that you have experienced so far, do you feel could change your motivation towards learning?”

As with any type of interview, there is always a risk that participants may be influenced by the interviewer's presence. Comments shared by interviewees may not be their definite thought or opinion, as the participant's environment may have an impact. Having been a student to some of the tutor participants and a tutor to some of the student participants, the familiarity and rapport between the lead researcher and the interviewees were different. The familiarity between an interviewer and participants would have impacted the degree to which opinions were shared and how honest those views were (Bell *et al.*, 2016). Some interviews gathered more detailed data than others; for instance, tutors spoke more freely about their experiences using the Pharma Compounds educational tool compared to the detail of student responses. Although some students provided limited responses, their responses were still insightful and provided essential perspectives on their experiences. In some cases, however, students did not expand upon their responses when asked to

elaborate. This may be due to the nature of rapport between the interviewer and participant groups. In relation to reflexivity, the relationship between the researcher and interviewees can have an impact on rapport and their responses to questions. Participants may have perceived some responses as “not what the researcher would want to hear” and therefore be reluctant to share these perspectives. In contrast, participants who experienced good rapport with the researcher may feel no reservations about sharing their honest opinions. There were some technical issues during one or two of the online interviews that were quickly resolved and did not prevent their progress. The video call interviews flowed well, and a substantial quantity of data was obtained for analysis.

10.12 Chapter Summary

The qualitative findings of the video call interviews were gathered via a purposive sampling method that ensured student and tutor perspectives from both sixth form and MPharm institutions were represented. Thematic analysis of the interviews resulted in the extraction of eight major themes; perspectives on education teaching methods and students' resulting confidence; perspectives on students’ motivation towards learning; perspectives on the Pharma Compounds AR educational tool; perspectives of similar educational tools; perspectives on improvements to the Pharma Compound AR educational tool; and perspectives on the implementation of the Pharma Compounds AR educational tool into educational settings.

Comments received from student and tutor participants suggested learners preferred teaching sessions that; required students to apply newly acquired knowledge, had discourse between peers and tutors, involved the use of technology, visual learning aids, and specific

teaching sessions that included material that could be directly contextualised into real-world scenarios. On the other hand, teaching sessions that resemble a didactic format were reported to be less enjoyable and stimulating. Confidence in knowledge was discussed in relation to the perception that students felt their level of knowledge was not at the level they perceived was required, whereas tutors felt students had a lack of confidence as a result of not reporting where they felt their knowledge was lacking, thus, they do not receive additional support.

Sources of motivation towards learning originated from a few areas, such as the desire to progress, achieve better scores, and fear of failure. Tutor participants also reported on these factors but added that they perceived students drew motivation from the desire to acquire more knowledge due to genuine interest in the subjects. Comments were also shared related to possible motivation changes and when these potential changes may occur. Student participants' comments seemed to be more short-term in their view of education in comparison to the responses of tutors. Some participants reported that their source of motivation would not change, whereas others, both students and tutors, recognised that a change might occur when learners acknowledge that they would need to learn to perform effectively as healthcare professionals. Motivation with respect to the AR educational tool was discussed, and comments were received related to favourable elements of current educational formats. Participants reported that the visual nature and interactive use of technology would continue to improve learners' motivation towards learning.

The Pharma compounds AR tool was to have improved learners' perceived understanding of educational content and hold perceived value in the education of the sixth form and undergraduate students. Participants commented on the 3D models aiding the visualisation of concepts that help to correct misconceptions of their knowledge. Participants reported that they believed the Pharma Compounds AR tool could have a wide application with improvements and additions to the educational content.

11 Discussion

11.1 Introduction

This final chapter focuses on the findings from the programme of work undertaken and its contribution to research investigating educational technologies' use. Section 11.2 details the key findings of this project in relation to the objectives stated in the aims and objectives chapter (Chapter 3.2). These findings are also discussed in the broader context of published literature in sections 11.3 and 11.4. The strengths and limitations of this study are explored in section 11.5, followed by reflexivity in section 11.6. Section 11.7 details areas for future research that involves AR in education. The concluding remarks of this thesis are documented in section 11.8.

11.2 Key Results

This research aimed to evaluate the effectiveness of an augmented reality educational tool (Pharma Compounds) in supporting the education of year 12 sixth form biology and chemistry students and stage 2 undergraduate MPharm students. The aim was met through a series of objectives, against which the findings will be discussed.

11.2.1 Design Objectives

The first three objectives of this research, related to the design and creation of the Pharma Compounds augmented reality educational tool:

- To identify specific aspects of year 12 biology and chemistry content that students and tutors consider difficult to understand and visualise.

- To identify specific aspects of Stage 2 Keele University MPharm content that students and tutors consider difficult to understand and visualise.
- To develop a series of AR Pharma Compound cards whose design and content was informed by participant data (objective 1 and 2) for year 12 biology and chemistry sixth form students and stage 2 MPharm students that will act as a learning/revision aid.

Responses to the intervention tool design questionnaires resulted in the identification of a series of year 12 sixth form biology and chemistry topics and undergraduate stage two MPharm topics that both students and tutors perceived difficult to learn (Chapter 5.8.2). These topic areas were cross-examined to identify mutually reported material that could contribute to the educational content of the Pharma Compounds AR tool. As expected, the topics suggested by undergraduate students and tutors were of greater difficulty than those reported by sixth form participants; however, some of the underpinning chemical and biological principles were relatable such as inorganic and organic chemistry topics, enzyme pharmacokinetics and chemical analysis (6.9.2). Other topics, however, were more unique (e.g., rheology, particle flow etc.) or did not lend themselves to be readily implemented into AR (e.g., quality assurance/ quality control, law and ethics topics etc.). Topics put forward by students and tutors were used along with the exam syllabi of participating schools to create an initial list of potential topics for the educational AR tool. However, due to limitations in time and resources, some of the proposed subject areas could not be completed in time to be included in the Pharma Compounds AR tool (Table 6.9, chapter 6.9.2). The majority of these topics, however, aligned with the MPharm syllabus and may have contributed to some of the responses gathered in the data collection process of the main study.

The qualitative responses from the main study broadly suggested that sixth form students may have found the educational content of the educational tool more useful than MPharm students (Chapter 9.5). Sixth form participants reported that their understanding of biological compounds improved with the educational tool. They did mention that the topic areas were limited and that the tool would become even more useful with a broader breadth of content. On the other hand, undergraduate participants did not report finding the content specifically helpful for the most difficult aspects of their learning; instead, they reported that the functionality of the educational tool would be of greater benefit should the content be more applicable to their studies. Some added that the current content would have been helpful at earlier stages of their education. As mentioned above, limitations in time and resources meant that the DDT were not able to complete the animation of some topic areas in both sixth form and undergraduate education, however, the majority of these topics were subjects suggested by undergraduate participants. Nevertheless, the topics included in the AR cards remained relevant to their education as tutors of sixth- and undergraduate students reviewed the final content list (Chapter 6.9.2). Participants revealed in the design intervention chapter (chapter 6.8.2) that the visualisation of concepts and phenomena is a factor that affects their ability to understand the material. This supports the findings presented in later results chapters highlighting the ability of the AR tool to provide visual representations, which contributed to improving and correcting students' understanding of educational material (Chapters 8.3.2, 8.5.2, 9.5, and 10.11). There were repeated reports from both sixth form and undergraduate participants that related to the functionality and interactive design of the educational tool. The visual nature of the Pharma Compounds tool was highlighted as one of the main features that

drew learners towards its use. In particular, placing two cards together to create a new target image was commented on by all groups of participants, including tutors, as something that could improve teaching sessions and reach set learning objectives. Findings from the intervention tool design chapter (Chapter 6) were not the only elements of this study that contributed to meeting this objective. Questionnaire and interview data revealed improvements participants would make in the AR educational tool to improve the learning experience. The most commonly reported improvement related to a broader range of educational content that covered more areas of the respective courses. The inclusion of audio and more complete animations were reported as additions which may increase the accessibility of the tool and help users better understand educational content within the app.

11.2.2 Knowledge-based Objective

The fifth objective of this study was to:

- To quantitatively and qualitatively assess the ability of the Pharma Compounds AR tool to enhance the knowledge of sixth form biology and chemistry and stage 2 MPharm students.

The results of the pre- and post-intervention knowledge-based quiz scores were presented and discussed in Chapter 6. The post-intervention mean, median and mode knowledge-based scores of sixth form biology and chemistry participants were either equal to or greater than the mean, median and mode scores on the pre-quiz. Although there was an

marginal increase in the pre- and post-knowledge-based scores, there was no statistically significant difference in either the sixth form or undergraduate scores.

A larger difference in mean pre- and post-knowledge-based scores was found for chemistry students as opposed to biology students, however, neither group showed statistically significant differences. The slightly larger difference in mean chemistry scores could be attributed to the style and content of the intervention tool – many of the 3D models incorporated into the Pharma Compounds tool displayed the chemical structure of biological molecules, reagents, and products of chemical reactions and, therefore, may be more suited to a chemistry syllabus as opposed to a biology syllabus. Regarding MPharm students, the pre- and post-intervention knowledge-based quiz scores followed a similar trend to that of the sixth form students. The post-knowledge-based mean, median and mode scores were either equal to or greater than the scores in the pre-knowledge-based quiz. Again, the differences between the pre-and post-intervention scores showed no statistically significant improvements in knowledge.

In four of the eleven MCQs, biology sixth form students scored better in the post-intervention quiz. All four questions showed a correct response growth of over 10%. Chemistry sixth form students answered seven of the ten questions in the post-quiz correctly at a higher percentage than on the pre-quiz. Four questions had a percentage increase of over 10%; the remaining three had a percentage increase of less than 10%. Concerning undergraduate MPharm students, 11 of the 19 questions had a higher rate of correct answers in the post-quiz compared to the responses in the pre-quiz. Five questions showed a percentage increase of over 10%.

The quantitative results illustrated no statistically significant increases in knowledge of sixth form and undergraduate students, performance in the post-intervention quizzes were almost identical to the performance in the pre-intervention quizzes. Furthermore, as discussed in the quantitative results chapter (Chapter 7), participation in the post-knowledge-based quizzes was lower than required to confirm statistical significance due to the COVID-19 pandemic.

11.2.3 Perspective-based Objective

The sixth objective set out:

- To qualitatively assess the perceived effectiveness, usefulness and useability of the Pharma Compounds AR tool in educational environments.

Findings from the questionnaires and the interviews related to this research objective. Perspectives shared on the Pharma Compound AR tool were expressed both in relation to its effectiveness and also in relation to what makes an educational tool successful. Students and tutors also commented on aspects of students' learning that may impact the confidence and motivation students demonstrate during the educational process.

The majority of comments detailed the visual characteristics of the educational tool. Both students and teachers had the impression that the visual capabilities greatly impacted the learning experience, with additional mention of further improvements that could increase its effect and utility in an educational setting. Those student participants who had

prolonged use of the educational tool commented how the visual representations aided the development of their understanding of new and old concepts that would otherwise have been more complicated to grasp. This links to reports from students who expressed that applying knowledge, particularly newly acquired knowledge, was an extremely beneficial exercise in their education. The Pharma Compounds AR tool allowed users to examine and apply their knowledge to 3D representations of new and familiar content. When used in sixth form group teaching sessions, it was reported that the Pharma Compounds AR tool offered opportunities for students and tutors to collaborate and discuss their understandings of the concepts detailed in the 3D representations. The tutor-student and student-student dynamic was stressed as a critical relationship, mainly in relation to discourse and feedback. This finding provides a very clear example of brainstorming as an active learning model as described in section 1.5.4. In groups, learners share their understanding on the topic being covered. In this scenario all comments are accepted, as through discourse, students can gain a better understanding of the topics, but Hmelo-Silver and Barrows (2008) found that it can also afford both students and tutors to identify gaps in the learner's knowledge, highlighting where more understanding may be required. Students reported that immediate feedback was another helpful practice as it informs individuals of their performance and ranking amongst their peers. It serves as a barometer of where they stand within their cohort performance-wise. Although personalised feedback was not offered by the AR educational tool, the opportunity to almost immediately use the tool to confirm one's understanding, as reported by MPharm students, provided an element of feedback for learners. Several questionnaire and interview responses from students and tutors highlighted the displeasure of didactic approaches as they often fail to engage the learner. However, there were responses in the pre-questionnaire and interviews favouring

tutor-led sessions such as lectures. Conversely, discourse-based learning approaches were reported to be more engaging and enjoyable for learners by both tutors and students. These comments reported during the interview highlighted that the opportunity for discourse was increased with the use of the Pharma Compounds AR educational tool. Discourse within teaching environments can be beneficial to learners, however, circumstances do not always allow for this type of approach (Gutierrez, 1995). As a result, didactic methods are frequently employed as they can deliver large volumes of information to a large cohort in a relatively short time (Berry, 2008; Gehlen-Baum and Weinberger, 2014). These findings

The novelty of AR was said to have contributed to an enjoyable and engaging experience that resulted in learners reporting to have had a better understanding and recollection of the subject material. Learners reported that the accessibility and mobility of the educational tool allowed it to be used in many situations and environments – in class, at home, and in a group or individual study session. This finding was linked to comments from tutors who discussed how incorporating technology was a key component of higher education and how it may considerably aid a student's learning process. Although the use of technology was reported to be encouraged by tutors who participated in this research, they all stressed that technology should only be used if it has application towards the studied phenomena and can enhance the learning process. Concerning the Pharma Compounds AR tool specifically, academic tutors commented on its ability to be a viable educational tool to deliver learning material. Many reports detailed that a educational tool would best be used in a blended learning approach to bridge the gap between the classroom and individual learning sessions. It was further explained that educational technologies should have utility in that

they should not only be a “nice to have” addition but also have a useful application in offering learners a different path to understanding the material.

Participants also commented on the limitations of the Pharma Compounds AR educational tool, most frequently, the range of educational content available. Although several participants reported the usefulness of the biology and chemistry-based material, comments were received that reported the content was somewhat limited. However, a large proportion of participants acknowledged the potential of this tool and even suggested additional content and functionality that would make the tool more applicable to other areas of study, such as anatomy and pathophysiology.

In addition to discussing perspectives on the AR educational tool, participants also discussed how elements of their teaching sessions affected their confidence in knowledge and motivation towards learning – the latter will be discussed in section 11.2.4.

Concerning perceived confidence, there seemed to be two different ideas of confidence. Both sixth form and undergraduate students discussed confidence in relation to their knowledge. They reported an increase in perceived confidence in their knowledge after being involved in teaching sessions that involved discourse and feedback (from either peers and tutors or assignments). Tutors, on the other hand, mainly undergraduate MPharm educators, discussed confidence regarding confidence in oneself. They felt as though their students lacked confidence in themselves and their abilities. This lack of confidence was reported to be a result of the students’ distorted perceptions of what they should be capable of at their level of education, ultimately lacking confidence in admitting to a lack of

knowledge. Although the student and tutor reports of perceived confidence may not be explicitly linked, they may be a relationship to be explored. Should learners exhibit greater confidence in their knowledge, would that then be recognised by their tutors as they may demonstrate more confidence in themselves and their abilities. The utilisation of more teacher-student and student-student discourse sessions could potentially improve learners' confidence and thus lead to improved tutor perception of learners' confidence in themselves and their abilities.

Students, particularly Pharmacy students, seemed to think they should be the 'finished article' during their time at university and did not realise that this was not the expectation of their educators. In addition, tutors highlighted that students are reluctant to ask questions as it can be perceived to signify a lack of knowledge, resulting in a negative spiral – students feel they are expected to know every area of a taught subject, so asking questions signifies a lack of understanding. By not asking questions, they do not get the clarification and more profound understanding they need to grasp what is being taught.

The perceived confidence in knowledge students possess may be fortified if they can identify the limit of their knowledge and are willing to expose the gaps in their knowledge. This again ties into the reports of opportunity for discourse between students and tutors brought about by using the AR educational tool. Additionally, tutors explained that students must recognise that they are not expected to fully understand and grasp concepts on the first attempt but build on their knowledge as the material becomes more familiar. That familiarity could be facilitated through the repetitive use of the Pharma Compounds AR

tool. The correct 3D models and animations of subject material would be presented to learners with every use of the tool, helping to confirm and clarify their understanding.

11.2.4 Motivation-based Objective

The fourth objective was defined as below:

- To quantitatively and qualitatively assess changes in self-reported motivation towards learning by sixth form students and MPharm students after the use of the AR Pharma Compounds tool.

The objective incorporated findings from the pre- and post-intervention questionnaire and the interviews with students and tutors.

Student participants were asked to self-report the levels of motivation they typically experience towards learning when involved in different teaching and revision sessions. Sixth form students rated their level of motivation as “motivated” when in laboratory sessions, workshops, demonstrations, sessions that utilise computer-generated simulations and their private revision sessions. The only type of learning environment associated with lower motivation than the others was lectures, in which students reported themselves as being neither motivated nor unmotivated. With respect to the MPharm students’ findings, participants reported being “motivated” when in teaching sessions that used computer-generated simulations, demonstrations, workshops and when in their own revision sessions. MPharm participants ranked their motivation towards learning as neither motivated nor unmotivated when in lectures and laboratory sessions.

Before being introduced to the intervention tool, sixth form and MPharm students completed a pre-questionnaire to measure their self-reported intrinsic motivation towards learning using their conventional methods. They were then asked to complete a second questionnaire after the intervention period focused on their self-reported intrinsic motivation towards learning with the AR educational tool. MPharm and sixth form students rated their self-reported motivation towards learning to be greater with the AR tool than without. Furthermore, the increase in self-reported motivation towards learning with the use of the Pharma Compounds AR tool was found to be statistically significant in both sixth form and MPharm participants ($t_{(23)}$=-3.056, p<0.05, and $t_{(30)}$=-5.89, p<0.05 and respectively).

The qualitative data gathered from the post-questionnaires and interviews provided perspectives on participants' motivation towards learning. These perspectives detailed many potential sources of motivation towards learning that students possess. Before introducing the intervention tool, student participants reported that their main source of motivation originated from one of two sources that would be positioned at almost opposite ends of a spectrum. Firstly, from a genuine interest in the subject matter, the desire to acquire new information, and to also progress academically. Secondly, at the other extreme, students reported wanting to achieve the best grade possible in their assessments and a fear of failure as two prominent motivational factors towards their learning. The comments of their tutors corroborated this. There were several reports that highlighted the role examinations and assessments play when addressing a learner’s motivation towards learning. Tutors explained that the format of particular assessments, such as MCQs, may

condition learners to place emphasis on retention rather than understanding. The focus on granular marks can occur even before university education, as entrance to many courses mainly depends on entrance examinations. Thompson (2016) suggests this process contributes to conditioning learners to focus on their ability to regurgitate memorised information in handwritten form within a time constraint. As mentioned in chapter 10.11, learners who focus on memorising and regurgitating facts limit their educational development. They may remain in the first levels of Bloom's taxonomy and Miller's Triangle (Chapter 1.5.3) and slow their progression towards the understanding and application of their acquired knowledge. The comments shared by interview participants directly tie into the limitations of Bloom's Taxonomy. Learners are left behind at the remember and understand stages, equipped with knowledge that that may consider to be unrelated facts. In an attend to stress the importance of progressing further along Miller Triangle tutor interview participants suggested that a change in the form of assessment may trigger a switch in the perspective of learners, from learning to remember towards learning to understand and apply. Quotes from Ramsden's 1984 research indicated that learners who had been successful in their degree studies felt uncomfortable relying on the surface-level strategy of memorisation to achieve top grades (Ramsden, 1984).

The qualitative data collected also explored if these sources of motivation towards learning could change and revealed both long- and short-sighted perspectives, which suggested changes may occur but may depend on the academic environment. For example, an MPharm student reported that the grades of assessments were always a significant source of motivation towards learning, going as far as to say, "*I don't know what else would change my mind."* This rather tunnel vision line of thought ignores the development one would

undergo once conventional academic education has been completed. Tutors also partly shared this perspective but added that for this ideology to change, the style of the assessments must also change. Assessments and assignments that are authentic and mimic reality could encourage a shift towards assessing learning rather than simply measuring the recollection of facts. Additionally, tutors recognised that as a learner progresses through their educational journey, particularly in healthcare practices, an individual would require acquiring knowledge and skills to execute specialist roles and procedures effectively. Therefore, the source of motivation would shift from accumulating granular marks and achieving good grades towards understanding knowledge and the correct execution of skills to carry out their role in practice effectively. The fact that tutors and not students were able to share this perspective may be a result of personal experience, whereas student participants had not yet gone through life experiences where this shift in motivation may occur.

11.2.5 Triangulation based Objective

The seventh and final objective was as below:

- To triangulate the perceived and statistical changes in both knowledge and motivation towards learning that can be attributed to the use of the Pharma Compound AR tool.

The results obtained from the sixth form and undergraduate pre- and post-knowledge-based quizzes did not show improvements in knowledge after the introduction of the AR educational tool; the marginal difference in score was not large enough to reach statistical

significance. These findings seem to conflict with claims made by both sixth form and MPharm student participants who perceived to have a greater understanding of the subject material after using the Pharma Compounds AR tool. This greater understanding of the subject material should have been reflected in the post-quizzes with improved scores, however this did not occur. The misalignment in perceived vs actual change in knowledge has been documented in literature. Many studies have reported similar findings and go on to report that participants had higher perceptions of their skills than their performance indicated (Bell and Volckmann, 2011; Lai and Teng, 2011; Versteeg et al., 2019; Ziegler and Montplaisir, 2014). This misalignment however may not affect all learners equally – top performing students have been shown to be more accurate at predicting their knowledge and performance in comparison to lower performing learners (Ehrlinger et al., 2008; Hacker et al., 2000).

A large proportion of students reported a perceived improvement in knowledge that they attributed to an enhanced ability to visualise phenomena due to viewing and manipulating the models through the AR educational tool. It should be mentioned that it seems as though the academic content built into the educational tool was unintentionally more suited to the sixth form students (6.9.2 and 11.2.4). Nevertheless, topics and subject areas provided by MPharm students who had already completed stage two of the course and tutors who had delivered material for the same year group were reflected in the educational content of the AR educational tool (Chapter 6.3). As a result, students may perceive content from some regions of the course as more useful than others. Should the tool implement a broader range of material, reported comments suggest that the perceived effectiveness of the tool may be greater than what has been documented in this thesis.

Statement 3 of the IMI Likert statement scores indicate that sixth form students were in greater agreement with their current learning/revision methods improving their academic performance compared to their agreement with the Pharma Cards bringing about said improvement. With respect to undergraduate students the opposite was identified. Changes in the knowledge-based quiz scores do not necessarily align with either group's attitudes towards their knowledge improvements and may offer further support of the misalignment between a learner's ability to accurately predict perceived vs actual knowledge changes.

As discussed in the methods chapter (Chapter 5.6), the pre- and post-intervention quizzes were online Google Forms and, as a result, when submitted, were automatically time and date-stamped. This feature allowed for the calculation of the "intervention period", the time between the completion of the pre- and post-intervention forms. Ideally, this period was to be a minimum of three months, however, this was not possible in every individual case due to the disruption caused by the COVID-19 pandemic, as explained in chapters 7.4.4 and 7.5.4. Although the time between the completion of the pre- and post-questionnaire provided participants with extended time to use and integrate the tool into the learning process, the knowledge-based quiz results showed a minor increase in knowledge. The post-questionnaire data collected asked participants to report how frequently they used the educational tool during the intervention period - both sixth form and undergraduate student groups reported having used it once or twice weekly (median Likert statement response). When comparing the length of the intervention period with the pre- and post-quiz scores, the non-significant changes in knowledge identified may have been due to the relatively infrequent use of the AR educational tool. Furthermore, the infrequent use may

have been driven by participants' perception that the educational content of the tool was somewhat limited compared to the variety of material they covered within their course.

There was no significant difference in the comparison of self-reported usefulness when using conventional learning methods or with the Pharma Compounds AR tool for both sixth form ($t_{(23)}$ = -0.685, p>0.05, chapter 8.3.2) and undergraduate students ($t_{(30)}$ = -1.562, p>0.05, chapter 8.5.2). However, both groups of students had mean post-intervention usefulness (usefulness of AR tool) agreement scores greater than the mean pre-intervention usefulness (usefulness of conventional learning methods) agreement scores. The reports from students gathered from the questionnaires and interviews suggested that although there were no significant differences between the pre- and post-IMI Likert usefulness subscales, students still perceived the AR educational tool to be and have the potential to be a useful tool in their education. Participants in the interviews also reported that the educational tool could be incorporated into several of their current teaching sessions, both at sixth form and undergraduate levels. In addition, several tutors reported how they believe this tool could offer students an alternative means to delve into phenomena and concepts that they currently deliver.

With respect to the self-reported motivation scores in the sixth form and undergraduate questionnaires, a statistically significant increase in the agreements to statements relating to motivation towards learning was found with the use of the Pharma Compound AR tool. This increase in motivation towards learning was further reported in the qualitative data from the questionnaires and interviews. Student participants reported having felt greater motivation towards studying with the introduction of the intervention tool. However, as

mentioned in chapter 9.5, some students reported that their motivation towards learning had not changed, which may indicate that using such technology in education does not benefit their preferred learning methods. On several occasions, students reported that the increase in motivation originated from the engaging and interactive nature of the educational tool. Tutors also reported that the nature of the AR educational tool lends itself to improving an individual's motivation towards learning – a number of comments from tutors detailed how the Pharma Compounds interactive functionality and engaging visual imagery aided learner motivation.

11.3 Educational Development

The academic knowledge of students is discussed in section 11.3.1, and their motivation towards learning in section 11.3.2. Section 11.3.3 details the importance of visualisation skills in education. These areas are explored in relation to research in this thesis and broader literature.

As highlighted in section 11.2.2, one of the objectives of this research was to identify any increases in participants' knowledge after using the Pharma Compounds AR educational tool. Statistical tests were applied to the data to identify any significant changes that may be attributed to the educational tool. The score indicated that there were no statistically significant increases in the mean knowledge-based quiz scores after the introduction of the intervention tool, the differences in the mean quiz scores were not large enough to suggest the tool could improve knowledge of participants.

Although the educational requirements of the sixth form and undergraduate students are not identical, they are sequential. The education sixth form students receive sets the foundation that is built upon once a student enters higher education. Although there may be differences in teaching methods (e.g. problem-based learning, teacher-centred instructional learning) between the two levels of education with different educational theories of pedagogy and andragogy, some theorists still prefer to focus on the unity of education where andragogy is simply another model of assumption to be used alongside pedagogy's – both pedagogy and andragogy are considered to be opposite ends of the same spectrum (Chapter 1.4) (Elias, 1979; London, 1973; Miller, 1973).

11.3.1 Academic Knowledge

Although no significant difference in knowledge improvement was found between the pre- and post-intervention quizzes of sixth form or undergraduate students, the innovative AR educational tool provided learners with the opportunity to encounter and manipulate phenomena and concepts that would otherwise be unobservable to the human eye; other educational tools like MolyMods® may offer learners the opportunity to view concepts but are restricted to only static chemical models that would have to be verified by tutors to ensure they are built correctly. In addition, the AR tool afforded students an additional avenue on top of their well-established methods to support their learning of course-specific material such as web resources, 2D diagrams, mind maps, and online videos. The ability to provide learners with the opportunity to view and experience concepts and phenomena that would otherwise be unobservable ties into Kolb's ELC. Learners enter the cycle from the 'concrete experience' stage when they view and interact with 3D models and animations of a phenomena on screen, gaining hands on experience that may otherwise be

difficult to encounter – that being models of chemical compounds as seen in the Pharma Compounds AR tool or animations that accurately reflect the movements of molecules and atoms during reactions. They are then able to reflect on their experience and then continue on to conceptualise a theory that can be applied to new interactions. It should be mentioned that this research's pre- and post-intervention format meant that the improvement in knowledge might result from the lengthy intervention period. In this period, external factors may have contributed to changes in the participant's knowledge. Over time learners may have become more familiar with topics, and thus their understanding may have naturally improved. Furthermore, some participants may rely on several different recourses and thus may have already been very familiar with the content rendering the Pharma Compounds tool not so integral to their learning process. Another point to highlight was the number of participants who partook in both the pre- and post-intervention elements of the knowledge-based quiz. The COVID-19 pandemic negatively impacted participation in the post-intervention quiz and caused significant disruptions to both tutors and students (the impact of the COVID-19 pandemic on this research will be discussed in more detail in section 1.5). That said, a clearer understanding of the AR intervention tool's effect on knowledge improvement may be found in an educational environment not disrupted by the pandemic and with a larger number of participants completing the post-intervention elements.

Research evaluating AR tools in education has found variable improvements in knowledge, including non-significant improvements (Herbert *et al.*, 2021) and significant improvements (Chang and Hwang, 2018; Chang *et al.*, 2015; Chen, 2019; Ferrer-Torregrosa *et al.*, 2015; Harun *et al.*, 2020; Liu *et al.*, 2019; Lu and Liu, 2015; Martin Gutierrez and Meneses

Fernandez, 2014; Yin *et al.*, 2013). Unfortunately, due to the effects of the COVID-19 pandemic, the sample size involved in this research was not large enough to identify any significant differences between participants' pre- and post-intervention quiz scores when their demographic categories were accounted for (gender, age, country of study). Although many pieces of literature investigating knowledge improvements caused by AR within biology, chemistry and pharmacy higher education recorded demographic data, few performed statistical tests that factored in demographic data.

Although sixth form education may not rely as heavily on experiential learning as healthcare undergraduates, various simulations have been proven to aid in acquiring knowledge and learning awareness (Herbert *et al.*, 2021; Kolb, 1984; Moro *et al.*, 2020). The affordance AR presents linking digital educational resources with the real world at the right time and in the right place can improve a learner's performance (Chiang *et al.*, 2014; Geng and Yamada, 2022; X Geng and Yamada, 2020; Xuewang Geng and Yamada, 2020; Küçük *et al.*, 2016). Comments received from participants and their tutors in this research corroborated these findings - using the appropriate cards, learners were instantly provided with text, images and animations explaining phenomena and concepts helping their perceived understanding. Such results may be explained using the spatial and temporal continuity principles of multimedia design theory proposed by Mayer (2001) and Mayer and Moreno (2003); learning scenarios that present relevant subject material in different forms (text, images, videos) in an organised and well-integrated fashion can prevent the creation of incidental cognitive load, thus benefitting students by improving their learning performance. This relationship was supported in a study by Habig (2020), where changes in the cognitive loads of male and female stereochemistry learners were compared after introducing an AR

educational tool. The authors hypothesised that AR representations would support all learners but provide additional support to females by reducing the cognitive load associated with completing spatial tasks. They found that both male and female participants performed as well as each other when completing non-AR-related stereochemistry tasks; however, male participants performed significantly better than female participants when completing AR-related stereochemistry tasks. The mean score for male students improved in AR-related tasks compared to their mean score in a 2D-related task, whereas the mean score for female participants fell slightly. When considering AR, students learn from the presented real-world targets and the additional digital AR material; both sources are integrated and organised to provide learning material in a manner that is aligned with the spatial and temporal continuity principles of the multimedia design theory, and therefore may reduce the possibility of creating incidental cognitive load (Chiang *et al.*, 2014; Mayer, 2001; Mayer and Moreno, 2003). This concept can be applied to the Pharma Compounds educational tool as the target images (physical cards) were designed to be contextualised with the computer-generated material of the system and the respective academic course material.

11.3.2 Motivation Towards Learning

A significant increase in self-reported motivation towards learning with the use of the Pharma Compound AR cards was found in sixth- and undergraduate students compared to the self-reported motivation towards learning prior to its introduction ($p<0.05$ in both sixth form and MPharm students). Both sixth form and MPharm students agreed with the use of mobile devices in their learning, with most participants reporting the use of technology as either important or very important in their education (chapters 8.3.3.1 and 8.5.3.2).

Interviews with MPharm students revealed that technology and mobile devices were encouraged during teaching sessions to aid learning. Therefore, students could extend that favour to the use of the Pharma Compounds AR tool as it revolves around the use of smartphones.

In the context of learning, motivation relates to students' desire to engage in their learning environment and is pivotal for students to engage in their learning and achieve higher academic performances (Budiman, 2016; Di Serio *et al.*, 2013). Previous literature that investigated the effects of AR in education and training showed that its use resulted in a consistently raised level of motivation towards learning over time (Martin Gutierrez and Meneses Fernandez, 2014; Yin *et al.*, 2013), a proportion of those studies found a significant increase in motivation (Budiman, 2016; Di Serio *et al.*, 2013; Nachairit and Srisawasdi, 2015).

The increase in a learner's intrinsic motivation when using AR educational tools has mainly been attributed to elements of curiosity, fantasy and control afforded by the technology (da Silva *et al.*, 2017), particularly as it has been described as an attractive and stimulating medium for learning (Gopalan *et al.*, 2017). These findings were also apparent in this research; both sixth form and undergraduate students and tutors reported that the interactive and visual nature of the educational tool, which utilises smartphones, lends it to be a familiar yet engaging tool and, as a result, could be a major factor in the significant increase in learners self-reported intrinsic motivation levels.

Previous studies have found that improved motivation towards learning was met with higher enthusiasm while interacting with AR educational tools; this, in turn, explained

higher reports of self-satisfaction, attention and confidence (Di Serio *et al.*, 2013; Santos *et al.*, 2016). The idea of confidence in one's knowledge was explored in the interviews; students and tutors reported that a lack of confidence could stem from insufficient feedback. This was mainly reported by MPharm students and their tutors concerning their conventional methods of teaching and learning. A lack of students' confidence to inform their tutors of gaps in their own knowledge goes unaddressed in fear of appearing unknowledgeable. This lack of confidence then spreads to the confidence in the learner's knowledge as they are unsure if they have the correct understanding, creating a spiral of low confidence. Zieber and Sedgewick (2018) surmised the relationship between the two phenomena and found statistically significant improvements in knowledge retention due to improving learners' perceived confidence. These findings tie into responses from both sixth form and MPharm participants' as they highlighted that feedback from peers and tutors alike helped to boost their confidence and correct their understanding of the concepts as they could gauge their level of understanding relative to their peers. Offering feedback to students that aid their understanding of their material would improve their confidence in their knowledge (Zieber and Sedgewick, 2018). These findings were reported by MPharm students and a sixth form tutor, who all explained how the use of the Pharma Compounds AR tool corrected and reaffirmed learners' understanding of concepts, thus improving their confidence in their knowledge. Through improved perceived confidence, participants in this study may have possessed greater application and drive towards their learning and thus may have contributed to comments of greater perceived and reported intrinsic motivation towards their learning. This cascade can be explained with the model for motivational instructional design presented by Keller (1987a, 1987b). Confidence within this model describes how a learner should build confidence by feeling in control of their learning and

having the expectancy for success as that will determine the degree of effort invested in the activity. As one of four elements, confidence, attention, relevance, and satisfaction (ARCS) are explored to determine motivational instructional design - greater effort leads to improved performance, which in turn leads to greater satisfaction.

11.3.3 Visualisation Skills

The perceived improvement most commonly attributed to the Pharma Compounds AR tool was the ability to visualise concepts. The use of visual aids in education has been widely used to assist in the teaching of theoretical concepts and phenomena that may otherwise be difficult for educators to relay to their students. More specifically, for chemistry-based subjects, many students, both at sixth form and university level can struggle to grasp the more complex aspects of the field that range from balancing equations to buffer solution calculations (Ali, 2012; Grove and Bretz, 2007; Orgill and Sutherland, 2008). In addition, educators have faced a problem delivering content of 3D structure of molecules and stereochemistry from 2D representations drawn in textbooks (Jones and Kelly, 2015). Nevertheless, the ability to visualise 3D representations from 2D drawings is a fundamental skill required not just in chemistry but also biology, mathematics and geography, amongst others (Lv and Li, 2015; Perdomo *et al.*, 2005; Silén *et al.*, 2008; Volino *et al.*, 2005).

More traditional methods of aiding learners' visualisation ability would be to use physical models such as ball and stick molecular kits for chemistry subjects or anatomical models of organs in biology (Battle *et al.*, 2010). As reported by student and tutor participants in this research, these tools may not always be available on demand to every learner. They can be time-consuming to distribute, set up and ensure each learner has the correctly assembled

model. Furthermore, using these tools would have been even more difficult during the pandemic, as students had minimal access to educational resources when studying from home. Institutions were forced to adopt a blended learning approach that has continued post-COVID, and therefore the availability of these models may continue to be restricted. Limited availability of such tools may reduce the opportunity for learners to reach higher levels of Bloom's Taxonomy to develop their skills of application and analysis of knowledge. 3D model representations and simulations through AR can combat these issues as technology has improved and become more accessible (Keser and Özcan, 2011). 3D representations used within AR systems have been shown to enhance learning experiences by making unobservable concepts visible; when used by educators during a teaching session, it can facilitate their role to actively encourage learner involvement in the education process (Azuma *et al.*, 2001; Dunleavy *et al.*, 2009; Krawczyk-Sta ̄do *et al.*, 2013; Wu *et al.*, 2013). Students can view and engage with content in a new format that allows for multiple perspectives on a concept, compared to what would be accessible in conventional educational environments. Visualisation of 3D augmented reality models has been shown to lead to a better understanding of phenomena as these models can be manipulated by the learner to offer views from different perspectives (Garrett *et al.*, 2015; Yuen *et al.*, 2011). Research has anecdotally shown that the visualisation of 3D molecules from many perspectives coupled together with the ability to manipulate the structures directly can support a more engaging and lifelike learning environment in mathematics, geometry and chemistry education (Fjeld and Voegtli, 2002; Kaufmann and Schmalstieg, 2003; MacCallum and Jamieson, 2017; Radu, 2014). AR has also been found to improve the memory of learners. Macchiarella *et al.*, (2005) and Macchiarella and Vincenzi (2004) found that the memory of academic material in university engineering students improved after using AR-

based learning practices, although the improvement was not found to be statistically significant.

Although the data collection tools did not explicitly collect data that related to the favoured VARK learning styles (Fleming and Baume, 2006) of participants (visual, auditory, reading/writing and kinaesthetic), data from some of the pre- and post-questionnaire loosely suggested what types of educational modalities students prefer. Results from sixth form students suggest they prefer visual aids followed by practical participation and the interaction between their colleagues and tutors. Undergraduate students on the other hand provided comments that suggest they prioritise the interaction between themselves, their fellow classmates and their tutors, followed by visual aids, then exercises which allow them to apply their knowledge. Although the VARK learning styles concept is popular, there was no clear justification to specifically capture data aligned to this learning model as literature had documented the controversies that surround it – researchers have reported: a lack of evidence for demonstratable learning styles using rigorous methods (Pashler et al., 2008); a lack of demonstrated validated measures (Hawk and Shah, 2007; Wehrwein et al., 2007); anecdotal evidence of students using their preferred VARK learning style as a crutch for not being able to learn through other modalities (Husmann and O'Loughlin, 2019). Studies have shown that learners who utilised learning methods that aligned with their preferred VARK category did not see any benefit in their learning outcomes and as such had been considered a waste of valuable time and resources (Awang et al., 2017; Husmann and O'Loughlin, 2019; Mozaffari et al., 2020). As a result, the decision was made to not focus of collecting data that would definitively explore this learning model.

11.4 Intervention tool design

The design of the Pharma Compounds AR educational tool was heavily commented on by both student and tutor participants and is discussed below in the following sections. Particular attention will be paid to the engagement and novelty of the educational tool (section 11.4.1), accessibility of AR (section 11.4.2), useability of the educational tool (section 11.4.3) and the Pharma Compound Integration into educational environments (section 11.4.4).

11.4.1 Engagement and novelty

Course engagement can be described as a student's active participation in the learning activities of their class or independent study (Skinner *et al.*, 2009). It is a complex concept with many layers to unpack that capture institutional practices and student behaviour, such as; student satisfaction and achievement, time spent on a task, social and academic integration, and teaching practices (Kahu, 2013). It is also a critical factor in a student's development as it can determine the success of their learning and the level of their achievement (Handelsman *et al.*, 2005; Kahu, 2013). Low levels of course engagement have been associated with a negative impact on a student's learning process and, thus, their course performance (Handelsman *et al.*, 2005). Therefore, researchers have investigated the use of educational tools to boost student engagement and encourage educators to adopt an array of pedagogical and technological approaches (Delello, 2014; Wang *et al.*, 2014). Higher education institutions have attempted to develop several educational technologies, not all digital, to integrate into their learning environments catering to the need and abilities of not only their diverse student population but also their educators (Georgina and Olson, 2008; Megahed and Hassan, 2022; Patra *et al.*, 2022).

More commonly, literature has conceptualised student engagement in three non-mutually exclusive domains; behavioural, cognitive, and emotional. The behavioural domain relates to the effort and persistence a learner exhibits towards their learning activities and degree of participation. The cognitive domain describes a learner's psychological investment towards the learning activity and the perceived value placed on what they are learning. Finally, the emotional domain refers to the emotional reaction towards the learning activity, both positive and negative (Baron and Corbin, 2012; Fredricks *et al.*, 2016, 2004; Nkomo *et al.*, 2021; Schmidt *et al.*, 2018). Although the three domains were not specifically explored in this thesis, data on student engagement with the Pharma Compounds educational tool was gathered. In particular, the emotional aspects, such as the sense of enjoyment and engagement experienced when using the tool, were repeatedly expressed by students in both quantitative and qualitative post-questionnaire data (sections 8.3.2, 8.5.2 and 9.4.2).

Students may have engaged with the Pharma compounds AR tool because they enjoyed its use. They highlighted the system's interactivity and the multiple onscreen functions as gratifying features. Literature has also shown that educational tools that feature AR elements were seen as enjoyable by the study's participants (Di Serio *et al.*, 2013; Ibáñez *et al.*, 2014; Lu and Liu, 2015). Although augmented reality as a medium in different sectors is progressively growing, it is still relatively new in mainstream educational settings. It has been suggested that improvements in learning that involved AR tools can be partly attributed to the novelty of the AR tool compared to more conventional educational tools (Albrecht *et al.*, 2013; Patzer *et al.*, 2014). As mentioned above, the emotional domain is a category that ultimately results in the development of engagement. The novelty of the AR

educational tool may have also contributed to participants' engagement with the educational tool. A large proportion of literature examining AR in education and training was conducted with a relatively short intervention period (Aw *et al.*, 2020; Gan *et al.*, 2018; Hou and Lin, 2017; Schneider *et al.*, 2020). This programme of research built on previous research by utilising a more extended intervention period in an attempt for reduce the phenomenon of the AR tools 'novelty' (Garzón *et al.*, 2019). The intention was to have an intervention period of at least three months; however, due to COVID-19 disruptions, most of the sixth form and undergraduate post-intervention quizzes and questionnaires were submitted seven months after the submission of the pre-intervention quizzes and questionnaires. Literature commonly reported a range of intervention periods ranging from a few hours (Gan *et al.*, 2018; Wozniak *et al.*, 2020) to several weeks (Chang *et al.*, 2016). One study, however, was carried out across an entire academic year (Keller *et al.*, 2021).

Student participants also expressed a slight increase in the self-reported usefulness and value placed on the intervention tool compared to the more conventional teaching methods. The behavioural domain in relation to the AR educational tool can be related to the frequency of use reported by each student (1-2 times weekly) and self-reported motivation to learn with the AR tool (Section 8.3.2 and 8.5.2). The ability of the Pharma Compounds AR tool to aid students' engagement in their learning activities can be supported by the findings of researchers who investigated the effects of AR educational tools on students' education. Delello (2014) and Dunleavy *et al.*, (2009), among other researchers, found AR educational tools to have had a positive effect on students' engagement towards their learning activities (Barrett *et al.*, 2018; Chen and Liu, 2020).

11.4.2 Accessibility

Access to educational technologies can facilitate independent learning and develop the information retrieval skills of learners (Bocconi *et al.*, 2006). For example, the in-app text windows of the Pharma Compounds AR tool that accompanied the 3D models provided immediate sources of relevant educational information for participants. The immediacy of which this occurred facilitated the information retrieval process of learners and may support independent learning – student post-questionnaire responses commented on how they utilised the immediacy of the tool quickly to confirm their understanding of a topic during individual revision. Accessibility, however, can present difficulties in connecting learners and educational content. From a technical standpoint, educational software technology can be categorised as either web-based programs that require internet access or locally executable programs such as the Pharma Compounds AR app (although it does require internet access to initially download or update the app). As mentioned in the introduction chapter, section 1.8, advancements in technology have meant that there are many high-quality hardware devices available that can contribute to an immersive AR experience (Chiang *et al.*, 2014; Dede, 2009). With respect to the software, developments have been made, but there are still only a limited number of cross-platform engines currently available – Unreal Development Kit, Godot, Engine, Cocos2D, MonoGame, Marmalade and Unity, among some others (Vakaliuk and Pochtoviuk, 2021). Those engines mentioned are said to have good support and technical performance on most devices; however, developers must also consider the ease with which programming code can be transferred between different platforms as well as the performance of the software engines on those platforms. The better the performance of the AR software, the more likely

developers can develop new, more dynamic, and immersive ways to present content. Thus, allowing educators to connect learners to new perspectives of concepts and phenomena.

The use of smartphones has become prevalent, and their functionality has rapidly improved while the cost of production has fallen, thus making them more affordable and a consumer favourite even in developing countries (Essel *et al.*, 2018; Iqbal, 2017; Iqbal and Qureshi, 2012; Kibona and Rugina, 2015). Worldwide statistics portray a picture where "generation Z" make up the majority of smartphone users (also known as digital natives) (Iqbal and Bhatti, 2020). This population group possesses a distinctive characteristic where they have an increased dependence on technology. The current generation of university students has been described as "skilled hunters" when gathering information (Iqbal and Bhatti, 2020). They read from one screen to another, sifting through different web-based reference materials rather than reading front to back, from one book to the next (Carr, 2011). The requirements of the modern "digital native" student are different when compared to the requirements of students of the past. Therefore educators should be aware of these requirements and be able to use the latest technologies to develop innovative pedagogies that will also accommodate the needs of the more modern methods of learners. However, educators would also need to ensure they are using "the right tool for the right job" and not using innovative technology that does not contribute to the value and delivery of educational material. When discussing the involvement of AR, not only should the system be detailed enough to meet the demands and practices of the "digital native", but it should also fit seamlessly into the pedagogies of educators.

Although there is a high prevalence of smartphone use in higher education, there seems to be a divide in opinion on adopting these devices in formal education environments (Iqbal and Bhatti, 2020; Tossell *et al.*, 2015; Yu and Conway, 2012). Some argue that smartphones are valuable and important tools to assist learning, whereas others claim these devices serve as a distraction (Alzubi, 2019; Mella-Norambuena *et al.*, 2021). The latter perspective was mentioned as a factor that should be considered when attempting to universally implement the Pharma Compounds AR tool (Chapter 9.4.2, table 9.4). Some students were concerned that some of their peers might become distracted by other applications on their devices when using the tool. It is also important to recognise that AR educational tools may present a similar drawback to the more conventional physical educational tools (e.g. ball and stick models). Not all learners may have access to a smartphone or tablet that can support AR programs and, as a result, will miss out on vital learning experiences. It is far less likely that this scenario will occur as students generally demonstrate better IT literacy now than in the past. Their access to compatible smartphones is greater than their access to other technological educational tools, especially in developing nations (Darko-Adjei, 2019; Kafyulilo, 2014).

Accessibility can be discussed in more than one way concerning AR. Firstly, AR can increase accessibility to unobserved phenomena and concepts by providing visual representations, as discussed in sections 11.3.1 and 11.3.3. The other perspective in which AR and accessibility can be discussed is its ability to include less abled individuals in the world around them. Students and tutors reported aspects of the AR system that could be improved to improve the accessibility of the Pharma Compounds tool to less abled learners. The addition of audio files was a common feature that users suggested would improve the

educational tool, and in turn, this feature would improve its accessibility to a diverse student population, ensuring inclusivity. These unique audio clips can be created to describe the 3D models/animations or to dictate the accompanying text. Audio has been used in other AR systems specifically developed to provide audio cues to help users perform specific tasks in the real world. For example, systems like Blindsquare and NavCog provided audio information about non-visual landmarks and points of interest to users of the system (Ahmetovic *et al.*, 2016; Herskovitz *et al.*, 2020). Additionally, AR systems have been developed and used to provide vital assistance for people who suffer from colour blindness, low vision, cognitive impairments and for coaching rehabilitation (Burke *et al.*, 2010; Gleason *et al.*, 2018; Kim and Dey, 2009; Tanuwidjaja *et al.*, 2014; Zhao *et al.*, 2020, 2017). The AR systems in these scenarios favour head-worn displays over smartphones as they augment the users' view and cognitive abilities via overlays on the view of the environment around them.

11.4.3 Useability

The useability of an educational tool is a critical element that needs to be considered when discussing integration into an educational setting, factors that affect its ease of use may directly impact the normalisation of its use. Therefore, before delving into the particulars of the wider normalisation of the Pharma Compounds educational tool (11.4.4), it is important first to explore the ease with which participants were able to use the intervention tool.

Most comments from students and tutor participants relating to the use of the Pharma Compounds detailed its relative ease. Participants repeatedly highlighted how quickly and easily they could access content once they had launched the app. During the development

of the educational tool, particular focus was also placed on including additional functionality that users could find helpful – onscreen buttons, molecule manipulation, changing virtual conditions (increasing or decreasing the pH of a molecule's virtual environment), and the combination of target images. Many AR tools evaluated in previous literature did not feature the additional content seen in the Pharma Compounds tool – onscreen interactivity and combining two target images to create a brand-new target (target a + target b = new target c). These features increased the tool's functionality and, therefore, could increase the variety of ways the educational tool could be used in an educational setting. This was reported in the post-questionnaire and interview results – e.g. As a reference tool alongside written theory, tutor-led classroom demonstrations of anatomy or chemical reactions, individual collaborative learning, and the introduction of a new topic, consolidation of a topic or the revision of a topic.

This research did identify aspects that impacted the useability of the educational tool. There were reports of some students failing to access the educational content; when attempting to scan a target card with the smartphone camera, a “black screen” was presented. Further investigation by the DDT found that this occurred in iOS and Android devices but most commonly occurred in the latter. The DDT at Keele University was informed and identified that the app required access to the camera of the device. It was suspected that the app's request to access the camera might have been denied on the user's phone resulting in the reported “black screens”. This information was relayed to participants immediately after the response from the DDT. Not having access to the educational content defeats the tool's objective and, therefore, would have negatively affected the system's useability. Feedback from students found that after uninstalling and reinstalling the app, they were presented

with notifications to allow the app access to the device's camera. Once approved, the Pharma Compounds AR tool functioned correctly. Another comment concerning the educational tool's useability was the variety of topics. Although students commented on the range of topics available, they highlighted that they would have liked to have seen content about more nuanced areas of chemistry, biology and the MPharm courses. The lack of variety in content, however, did not reduce the educational tool's reported useability, as many participants incorporated the system into their study habits.

11.4.4 Integration (Normalisation Process Theory)

Despite the rapid and significant development of both software and hardware, educators had previously been somewhat reluctant to use newer technologies in their daily teaching (Fraillon *et al.*, 2014; Njiku *et al.*, 2019; Nordlöf *et al.*, 2019; Semerci and Aydin, 2018; Wastiau *et al.*, 2013). The use of educational technologies had not only been limited due to the attitude of educators but also by pedagogical approaches as the switch from traditional teaching methods towards student-centred approaches provided some challenges, such as; switching students' mindsets from passive, educator-directed learning to active student-directed learning; time management of educators; consistency of implementation across educators (Aslan and Reigeluth, 2015; Voogt *et al.*, 2013). For over 30 years, researchers have attempted to understand the process and conditions required to successfully normalise the use of digital technologies in the education sector (Petko *et al.*, 2018). Since the COVID-19 Pandemic, however, educational institutions have been forced to close to combat the health crisis; educators were forced to rely heavily on newer educational technologies as online distance learning became the primary way to educate students (AlAjmi, 2022; Bourgault *et al.*, 2022). As such, the acceptance and use of educational

technologies were forced upon educators and learners, which improved digital literacy skills (AlAjmi, 2022).

The Normalisation Process Theory (NPT) was used in this study to understand the conditions under which the intervention tool may be seamlessly incorporated into daily use in educational settings. Concerning the Pharma Compound cards, the framework helped to address factors that played a role in how the educational tool was and could be used by tutors and learners individually, but also exploring their use in education more widely. Digital interventions are considered complex due to several interacting components that include changes in individual, group systemic and organisational behaviours (Moore *et al.*, 2015). However, the new practice becomes normalised once it is routinely utilised in the daily education of learners. This theory is built on four main components; the first is "coherence", relating to the individual and collective understanding of the new technology. The second is "cognitive participation", referring to the engagement and commitment from participants to use the system. The third construct is "collective action", which details the actual use of the Pharma Compounds AR system and factors that affect or inhibit its use. The final construct, "reflexive monitoring", relates to participants appraising the system and its impact (Ong *et al.*, 2020; Scantlebury *et al.*, 2017). Although briefly mentioned in chapter 9.11. the constructs are not mutually exclusive but share a dynamic relationship and will be explored in more detail below.

The overwhelming majority of students who were introduced to the Pharma Compounds AR system reported enthusiasm and were visibly excited to receive the educational tool – students smiled and instantly began to talk to one another about the AR tool when they

were given a demonstration of how to use it, some even said “wow” and “that’s cool” out loud during the demonstration. Individually, participants understood the purpose and rationale behind the Pharma Compounds AR educational tool; they could distinguish the novel tool from other educational technologies and detailed its role in their learning. From the individual responses of participants, it could be said that collectively participants' perspectives of the purpose and rationale of the educational tool aligned. Questionnaire and interview responses from participants revealed a uniform understanding that the tool was designed to provide learners with a perspective of unobservable concepts being taught and the opportunity to manipulate the 3D visual representations, all to aid the understanding of perceived difficult topics to learn (coherence).

There were various “cognitive participation” examples by both groups of students and tutors. Participants reportedly recognised where this tool would position itself in their learning. Some MPharm students highlighted that the tool would hold great value if it were used earlier in their education of fundamental chemistry and biology elements in the MPharm course. Regarding sixth form biology and chemistry education, the value was explored compared to existing educational tools that help learners visualise the material. The reduced time spent ensuring learners had built and were looking at the correct 3D chemical models was highlighted as an advantage over tools like MolyMods®. Students mainly focused on the individual value the Pharma Compound educational tool would bring towards their education personally, whereas the tutors who were interviewed addressed the collective value this educational tool could bring to the education of their students. Tutors discussed different exercises and scenarios that the Pharma Compound tool could be used in, for example, building unique chemical compounds using multiple target images

(would require programming but is possible) or use in pharmacology lectures and workshops to help students understand the cascade of drug and hormone receptors within the body. There were also suggestions that it could demonstrate the differences between healthy organs and organs suffering from co-morbidities and demonstrate how to correctly use medical devices, such as asthma inhalers or nasal sprays. It was immediately apparent that tutors could find a wide range of applications for this tool in their teaching sessions. Upon being introduced to the educational tool, a sixth form tutor proposed a staged approach when using the cards – initially, have the students look at the 2D image on the cards and discuss that representation before moving on to the 3D models. Undergraduate MPharm tutors reported that the tool would be favourable to students as it has immediacy; it can be used in teaching sessions or at home, particularly with the implications caused by COVID-19. As mentioned in the Interview results chapter, not all tutors were able to use the AR tool in their teaching but were able to share their perspectives on it. MPharm tutors, particularly, reported on the utility of the tool, claiming that it has wide application in various areas of teaching, including anatomy, pathophysiology, drug mechanisms of action, question and answer sessions, problem-based learning, integrated into online learning environments, counselling patients on the use of medical devices, and even as far as the education of nursery children.

This discussion did raise a critical point that is core to the success of educational tools as a whole; it must add value to the educational process. That value must be seen not only by students but also by educators. In the scenario of the Pharma Compound tool, educators reported in the interview that they and their colleagues must believe that the educational tool would seamlessly fit into their teaching methods to be used repeatedly; otherwise, the

significance of the tools use will be lost as just another “flashy nice to have distraction” (Chew *et al.*, 2018). Further to this point, an MPharm tutor stressed that in order to create a seamless fit, educational technologists and educators would need to work together to create a tool that fulfils the requirements of the educators teaching methods, similar to the process that resulted in the creation of the Pharma Compounds AR tool (chapter 6).

This framework then transitions towards the ‘collective action’ construct. Similar to cognitive participation, a range of responses related to the third element of the NPT. The greater the relevancy of the educational tool to the teaching methods and requirements of both educators and students, the greater the support for the intervention – support for the intervention relates to factors that are required in order for the educational tool to be successfully integrated into an educational environment (Chapter 9.10). Sixth form students experienced this to a greater degree as their tutor explained they usually have a period of their class where students explain recently taught concepts to one another to ensure they have the correct understanding and proceeded to use the AR tool in this capacity to recap and refresh students understanding of the topic areas. However, undergraduate students did not report such experiences, which may have related to the relevancy of the educational content and the stage of the MPharm students' curriculum. Both sixth form and undergraduate students mainly reported using the tool one to two times a week, often during their revision sessions. This finding does not directly align with reported use of AR in literature. The majority of study designs implementing AR, mainly involve specifically curated AR classroom teaching sessions or activities (Chapter 2.4.4) (Behmke *et al.*, 2018; Reeves *et al.*, 2021; Salem *et al.*, 2020; Sanii, 2020; Schneider *et al.*, 2020). The frequency of use the AR tools use is directly linked to the collective action construct of the NPT

framework. Unfortunately, there was no data collected regarding the time participants spent using the app. Although this may be considered a limitation, this level of sophistication would have required significantly more development time for programming. Ways in which the tool can be improved to increase the likely hood and frequency of its use is discussed below when exploring improvements. There were also students reporting to have used the physical cards similar to how they would use flashcards, recalling relevant information when presented with the 2D images on the cards.

Concerning reflexive monitoring, there was not a large variety of responses compared to the other three constructs. After the intervention period, students and tutors commented on the perceived benefits they believed to be associated with the AR tool. The reported benefits already mentioned throughout the results and findings of this thesis highlight the visualisation of concepts as the most frequently reported benefit, followed by the engagement students displayed. Participants also commented on what they believed would be potential benefits should the tool be adapted to other areas of their courses. For example, an undergraduate student reported that they would experience a greater desire to participate in their learning as they felt the introduction of AR tools like the Pharma Compounds system would demonstrate greater investment in their education on behalf of their university.

May *et al.*, (2016) offered an expansion to the NPT that placed it in relation to understanding context as a process. This expansion stemmed from the concept of complex adaptive systems that consisted of different participants and elements that are interactive dynamic, and dependent. As a result, the constructs of NPT are related to the context in a

manner that would mean implementation could be a non-linear process (Ong *et al.*, 2020). Furthermore, the inclusion of feedback loops and negotiations further supports the non-linear nature of implementation. Taking those factors into consideration with regards to the Pharma Compound AR system means that the collective action (use of the AR tool in classroom settings, at home, in group and individual learning sessions), the varied application, the broad range of content that can be augmented through this media (e.g. anatomical structure, the addition of text and sound media, animation clips, interactive function), non-reliance on the internet to access educational content and the ability to add new updated content via feedback from users in the form of app updates (updates would require an internet connection) (feedback loops) created a context that would be favourable for consistent implementation.

Improvements in the functionality and performance of the AR educational tool can only contribute to its acceptance, usage and ultimately, normalisation, into wider educational settings. Questionnaire and interview data revealed a number of suggested improvements which both students and tutors believed would increase the likelihood and frequency of its use as an educational tool. The most commonly reported improvement participants would make to the Pharma Compounds AR educational tool related to the range of educational content. Students reported that they would have liked to have had material that was not only based on the molecular biology or chemical structure of molecules, but broader topics that they would encounter on their respective courses. MPharm students particularly commented on nuanced material such physical anatomy, drug mechanisms of action and pathophysiology. An additional improvement suggested by participants surrounded the functionality of the tool. Participants suggested smoother animations that would clearly

demonstrate exactly how two molecules would come together and react with one another as opposed to “snapping” together. As mentioned in section 9.5, the development and content of the tool was restricted due to limited development time and resources. The addition of quizzes/questions or gamification was also a suggested participants in both the post-questionnaire and interviews. Gamification is a popular feature of AR systems used in published literature with the aim to engage learners (Argo et al., 2019; Hensen et al., 2018; Moreira et al., 2017). This feature would also provide learners with the opportunity to immediately test their knowledge and understanding of material. Moreover, interview participants went on to report that the addition of audio to explain the on-screen models and animations would further improve the tool, broadening its scope and accessibility towards individuals who may require further support. Improvements such as those reported by participants will inevitably improve the features and functionality of the tool and therefore learners and tutors may find more opportunities to use the AR tool in educational settings. Increasing the opportunity for use may lead to an increase in the frequency at which participants used to tool.

As explained previously, NPT contributes to the likelihood of a complex intervention being successfully adopted into a social system. Although this study was conducted with a relatively small group of participants, it has shown great promise. Comments from participants allude to the Pharma Compounds AR tool being successfully incorporated into a wide range of educational settings providing the content is relevant to the teaching. The AR format of the system was received well by both students and tutors as something that would contribute to a better understanding of concepts and phenomena. Both parties could identify an effective use for the tool to display 3D visual representations of educational

material to support their learning during teaching sessions or revision. The most important factor highlighted by participants involved the collaboration of educators and educational technologists to create content that aligns with the educator's teaching practices and methods. Thus, should the Pharma Compounds AR system be launched within a similar context, it would have a favourable chance of successful implementation.

The level of coherence, cognitive participation and collective action can also be improved as a result of making improvements that are brought about by reflexive monitoring. Should the improvements suggest above be implemented, both students and tutors understanding of the Pharma Compounds tool role and function in education will become clearer (coherence). Both learners and educations could envisage new and novel ways to engage with the AR tool (cognitive participation). As a result, the way in which the tool is used may improve (collective action). Which then leads to users reviewing their experience (reflexive monitoring) starting the cycle again. As with any form of technology, developments and improvements in both hardware and software occur at a rapid rate and as such there will be improvements that can be made to the AR system that were not discussed at the time of this research.

11.5 Strengths and Limitations of the Research

The research carried out in this thesis contributes to the limited researched topic of augmented reality educational tools in biology, chemistry and pharmacy higher education (Maryam Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Salem *et al.*, 2020;

Sanii, 2020; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Sirakaya and Alsancak Sirakaya, 2018; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020; Yang *et al.*, 2018; Yapici and Karakoyun, 2021). Investigating AR educational tools' effect on a learner's knowledge or motivation is not an entirely new investigated area (Chiang *et al.*, 2014; Dunleavy *et al.*, 2009; Khan *et al.*, 2019). However, this thesis did include a new perspective by exploring the phenomena in both sixth form students (biology and chemistry) and undergraduate MPharm students. A large proportion of published literature focused on the development of AR educational tools but did not investigate the effects they have on learning (Ba *et al.*, 2018; Hoog *et al.*, 2020; Maier *et al.*, 2013; Martin-Gutierrez *et al.*, 2015; Qamari and Ridwan, 2017; Sharmin and Chow, 2020).

This study encompassed the development of the AR educational tool, the subjective and objective effects it had on learner knowledge and their motivation towards learning, as well as its ability to be integrated into mainstream educational environments. The pragmatic nature of this study contributed to providing a comprehensive and detailed insight into the affordances and magnitude such an educational tool could bring to the education sector should it be widely adopted (Frost and Nolas, 2011). The results regarding knowledge changes quantified the AR system's objective performance as an educational tool. The pre- and post-questionnaires obtained a standardised perspective on the changes in self-reported motivation towards learning and perceived changes in the value of the educational tool (Phellas *et al.*, 2011). The open-ended questionnaire questions and the one-on-one semi-structured interviews allowed for the collective Likert scale responses to be contextualised and expanded on the general themes to gain a richer understanding of attitudes and perspectives (Johnson and Turner, 2003). The inclusion of tutors in the one-

on-one interviews and the analysis of NPT provided an additional layer and tied the knot on the threads of the conception, creation, evaluation and implementation of a novel AR educational tool (Murray *et al.*, 2010).

A wide range of experimental procedures has been used in the published literature that explored the use of AR in education and training, most commonly questionnaires and knowledge or performance-based assessments (Maryam Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Salem *et al.*, 2020; Sannikov *et al.*, 2015; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020; Yapici and Karakoyun, 2021). This research project employed both of these methods in a pre- and post-intervention format with the addition of one-on-one interviews (Aw *et al.*, 2020; Hou and Lin, 2017; Schneider *et al.*, 2020; Wong *et al.*, 2020). The combination of all the mentioned data collection tools not only contributes to the strength of the findings but also supports the use of similar research methods that can be used to evaluate AR in academic education (Gurbiel, 2018; Udo Kelle *et al.*, 2019). As mentioned in chapter 4.3.3, the combination of quantitative and qualitative data collection tools can compound the strengths of both disciplines while minimising the limitations associated with each approach - quantitative data can lack context, so the inclusion of qualitative data collection tools that explore views and perspectives of participants can provide context to the quantitative findings.

There was a diverse range of student respondents in relation to age, gender and level of study. All of which contributed to the robustness of the research findings, as mentioned in chapter 4.6.2 (Shadish *et al.*, 2002). Participants were recruited from sixth form schools and colleges from two countries and a school of Pharmacy in the United Kingdom. Having students from different countries, different types and levels of education afforded the comparison of responses, perspectives, and uses of the educational tool, further strengthening the findings.

Concerning the data collection tools used in this programme of research, many have been utilised in studies that investigate AR in biology, chemistry and pharmacy higher education (M Abdinejad *et al.*, 2021; Aw *et al.*, 2020; Behmke *et al.*, 2018; Chang and Yu, 2017; Gan *et al.*, 2018; Habig, 2020; Hou and Lin, 2017; Keller *et al.*, 2021; Macariu *et al.*, 2020; Núñez *et al.*, 2008; Ovens *et al.*, 2020; Reeves *et al.*, 2021; Rodriguez *et al.*, 2021; Safadel and White, 2019; Salem *et al.*, 2020; Sannikov *et al.*, 2015; Schmid *et al.*, 2020; Schneider *et al.*, 2020; Smith and Friel, 2021; Wong *et al.*, 2020; Wozniak *et al.*, 2020; Yapici and Karakoyun, 2021). Beginning with the knowledge-based MCQ quizzes, all questions from both quizzes were taken from past examination questions approved by the following public Biology and Chemistry A-level examination board websites; AQA, Edexcel, CIE and OCR. The questions were adjusted but only to prevent repetition and the possibility of participants encountering the same questions in their examination preparation. Before being finalised, both quizzes were reviewed by tutors and the supervisory team to ensure their correctness. With respect to the questionnaire, the motivation Likert scales were again adapted from the IMI that had been validated in several studies which evaluated intrinsic motivation towards a specific activity (Bryce *et al.*, 2018; Choi *et al.*, 2009; Markland and Hardy, 1997; McAuley

et al., 1989; Monteiro *et al.*, 2015; Nieuwhof-Leppink *et al.*, 2019; Plant and Ryan, 1985; Takeda *et al.*, 2017; Williams *et al.*, 1998). The original tool had previously been tailored to accommodate a wide range of activities and can be adapted for use in many different scenarios by simple alterations to the Likert items (Choi *et al.*, 2009; Monteiro *et al.*, 2015). Finally, the semi-structured interviews were designed to explore the responses to the questionnaire data (McAuley *et al.*, 1989; Ryan, 1982). The questions documented in the interview guide were adapted from and based on a series of statements contained in the NPT framework (Murray *et al.*, 2010). Additionally, semi-structured interviews were intentionally chosen as they offer the flexibility to explore new themes and ideas put forward by participants (Braun and Clarke, 2013).

Despite the many strengths in how this study was designed and carried out, some limitations must be acknowledged. The first of which was the lack of a pilot study. Pilot studies are often conducted to refine data collection tools ensuring they are appropriate to the aims of the investigation (Drennan, 2013a; Roopa and Rani, 2012; Schwarz, 1995). The use of a pilot study may have provided some insight into the challenges faced during the participant recruitment and data collection stages of this programme of research. Although every attempt was made to recruit sufficient participants such that sample size was large enough to determine statistical significance, the pilot study may have revealed whether the methods of recruitment were feasible to achieve the estimated recruitment target. A pilot study may have also revealed the rate of participant drop out after each phase of the data collection process, and as such, adjustments could have been made to recruit further participants from varied demographic backgrounds. Furthermore, the use of a pilot study may have provided some feedback on the content of the AR card that could have been

addressed prior to the beginning of the main study. As mentioned in chapter 4.6.2, the quantitative elements of the data collection tools had been adapted from previously validated instruments (IMI and past public examination board exams). Furthermore, the qualitative interview questions were also based on and adapted from the well-established NPT framework. The second limitation relates to the pre- and post-intervention format of the MCQ quizzes. Although this format allows researchers to gather baseline data that can be compared to data gathered after the introduction of the intervention tool, the difference in results may have been impacted by various variables. Such as an extended intervention period, students becoming more familiar with the educational material of their courses included in the AR tool. Furthermore, some student participants may ordinarily use a multitude of different resources during their learning process and may have continued using them during the intervention period. This familiarity over time and using other educational resources may have contributed to improvements in their knowledge and understanding.

A third limitation was the reduction in participant responses as the study progressed. Participation dropout has long been associated with phased research, and this study was no different (Pratt *et al.*, 2000). The response rates after the intervention period were 34% in sixth from participants (post-quiz) and 43% in undergraduate participants (post-quiz). The lead researcher attempted to maintain good contact with all participants by consistently sending emails to participants and their tutors, reminding them of the online forms still to be completed. In addition, it cannot go without mentioning the impact the COVID-19 pandemic had on this piece of research from the beginning of data collection right through to the end. Three additional sixth form colleges were due to participate in this study, two public sixth form colleges based in the UK (approximately 120 students in total) and one

private sixth form college based in Hong Kong (33 students) (section 5.2). Unfortunately, due to the COVID-19 social distancing requirements and resulting temporary closures of the schools, they were unable to participate. It would also be fair to say that the disruption caused by the pandemic may have affected the response rates of participants involved in the study. Disruptions and the uncertainty of what would occur in the immediate future of students' education made it extremely difficult to execute the post-intervention elements, as the lead researcher could not make in-person visits to the post-questionnaire and post-quiz completed. Instead, these elements were emailed to participating students along with a significant number of reminder emails. Unfortunately, these efforts were not sufficient to maintain high response rates. A new piece of research has shown that its current research participants perceived COVID-19 as a significant threat, affecting their mental health, desire to participate in research, and ability to adhere to intervention recommendations (Cardel *et al.*, 2020). Nevertheless, statistical tests were still able to be performed; the specific test depended on the number of participants who occupied each demographic category (Chapter 5.8.2).

A limitation that became apparent from this research's findings was the Pharma Compounds AR educational tool. The limited educational content relating specifically to the MPharm course may have impacted the responses from Pharmacy students. Although the tool's content had relevance to their course, the inability to implement specific topics suggested by students and tutors may have had a negative impact on students' perspectives on the tool's relevance to their education. An additional limitation that appeared as a result of this study's findings, related to the misalignment between the objective and perceived improvements in learners reported knowledge. Literature has documented how learners

often overestimate their perceived level of understanding and knowledge as their reported levels of improvement do not routinely match with objective changes in knowledge (Bell and Volckmann, 2011; Lai and Teng, 2011; Versteeg et al., 2019; Ziegler and Montplaisir, 2014). This observation was also apparent in this programme of study, learners reported improved perceived levels of understanding and knowledge however it was not reflected in their objective quiz scores. Therefore, relying primarily on the perceived reports of learners would not be the most reliable findings and would need also need corroboration with objective findings.

11.6 Reflexivity

Reflexivity and the theory behind the construct were discussed in detail in the methodology chapter, section 4.6.3. This section of the discussion will explore the potential effects the lead researcher may have had on the research outcomes throughout the project.

To begin with, the lead researcher took advantage of links to sixth form schools associated with the supervisory team and the university as a source of participation. Beginning with the development of the Pharma Compounds AR tool, the lead researcher intentionally contacted these institutions to enquire about the availability to be included in this study. Schools that were situated locally to the university were visited in person, and students, as well as tutors, were invited to answer an online questionnaire collecting data that would be used to help inform the content of the educational tool. The international schools were contacted via email with an attached link to the online questionnaires. The association with the university and members of the supervisory team may have increased the willingness of these schools and colleges to participate in this study initially.

This was also true with the involvement and participation of undergraduate MPharm students. The lead researcher visited the entire stage three cohort after a teaching session to give a brief presentation on the project and its aims before inviting them to complete the online questionnaire that provided data for the AR tool's creation. The familiarity between the lead researcher and these participants must also be noted, as the lead researcher previously attended the same institution and was involved in teaching and assessments.

With respect to the main study, participants were recruited in a very similar fashion, taking advantage of the involvement of institutions in the previous phase of the project. The lead researcher visited sixth form colleges and undergraduate teaching sessions to deliver a presentation detailing the project. The lead researcher's physical presence and their colleagues' involvement in the previous stage of this study would also have some bearing on the willingness of both MPharm and sixth form students to participate as the pre-intervention elements were completed in the same face-to-face visit.

Having also recently been in the position of many students, particularly the MPharm students, the lead researcher understood many of the demands participants would encounter during their education. As a result, participants may have had the impression that a project focusing on improving the educational process presented by an individual who was recently in their position would have yielded benefits for their education.

The final element of proximity and familiarity in this study related to the recruitment and execution of the one-on-one interviews. A proportion of the tutors recruited for the

interviews were previously known to the lead researcher because they were an undergraduate student at Keele University in the recent past. As such, the familiarity between the two parties may have encouraged their eagerness to contribute to this study and offer favourable comments about the intervention tool. Additionally, the nature of video interviews also carries an element of reflexivity that must be highlighted. As discussed in the methodology chapter (4), responses to questions in the face-to-face interview may be skewed or may not be the participants' genuine perspective due to the interviewer's presence. Despite this, the interviews gathered both positive and negative responses to the AR tool and experiences with its use which may indicate that both tutors and students were comfortable sharing their true thoughts on topics discussed.

It should also be stated that data collected in qualitative research is subject to the personal thoughts and feelings of the researcher and has a socially contingent nature. Therefore, the thoughts and feelings of the lead researcher may have influenced how this study was carried out and the analysis of the results. The volume of data collected in this study required the lead researcher to utilise their time management and organisational skills to ensure data management, processing, and interpretation occurred while ensuring subsequent phases of the study progressed promptly. As such, there may be a possibility that relationships between particular themes could have been missed or responses misinterpreted despite the rigorous analytical processes that were carried out. To minimise the possibility of this, the lead researcher reviewed the codes included in sub-themes and over-arching themes several weeks after the completion of the analysis of the data. Themes, sub-themes, and codes were discussed with the supervisory team also reduce the possibility of data misinterpretation. The lead researcher throughout this research project

made reflective notes. The notes documented a variety of elements regarding this study – from notes on the rationale for choices and amendments to the study design and data collection tools to notes during the data collection and analysis process documenting critical responses (Chapters 5.7 and 5.8).

11.7 Future Work

This section of the thesis will explore additional findings that require further exploration in future work.

Sixth form students reported a greater sense of value in using the Pharma Compounds AR tool compared to the value of conventional teaching methods. Stage two MPharm students and tutors also shared this perspective. The chemistry and biology topics taught in sixth form colleges form the basis for many pharmacodynamics and pharmacokinetic topics in the first two years of the MPharm course. Aside from this, students are also taught the pathophysiology and treatment pathways of many frequently encountered conditions. As the course progresses, more weight is placed on these aspects. As such future work could investigate the use of AR in the delivery of education, focussing on the pathophysiology and treatment pathways for more senior Pharmacy students. This work could also include the education of foundation pharmacists in their preparation to sit the registration examination.

Additionally, AR could be used to enhance the education of patients with regard to their medical conditions. Ensuring patients understand their condition and treatment plan

correctly is vitally important in maintaining high patient adherence. An AR system that displays the correct counselling points on patient conditions, medication, and medical devices such as asthma and the variety of inhalers could potentially improve patients' understanding and treatment experience. Therefore, methods and tools that could aid this process should be investigated to improve patient education. For example, with respect to the Pharma Compound AR tool, target image cards that display a medical device would trigger the mobile app to display a 3D animation that demonstrates the correct way to administer a metered dose inhaler, eye drops, or nasal spray. Text and audio could also accompany the animation to provide further instruction for each step of the administration process.

A number of sixth form students reported having enjoyed their experience using the Pharma Compound tools stating they would like to have a similar tool in other subjects they study at college. Future work could include developing and investigating AR tools on other non-science-based subjects.

This programme of research investigated the effect the Pharma Compounds AR educational tool has on motivation toward learning using Likert scale questions adapted from the IMI. This multidimensional tool measures intrinsic motivation and is one of many tools that can be used to evaluate the level of motivation towards a target activity. Another such tool is the Instructional Materials Motivation Survey (IMMS), which assesses the motivational characteristics of instructional materials through four constructs – Attention, Relevance, Confidence and Satisfaction (ARCS). Should future research into motivational changes caused by the Pharma Compounds AR educational tool be investigated, the ARCS model

should be employed. Findings from that potential study would reveal what specifically about the educational tool would improve motivation towards learning and further corroborate the findings in this thesis.

As already mentioned, the COVID-19 pandemic had an enormous impact on participant numbers during the data collection process, and subsequently impacted the ability to identify whether changes in knowledge due to the AR educational tool reach statistical significance. Therefore, future work involving the Pharma Compounds AR tool should also include a larger-scale study than the one carried out in this thesis to investigate changes in knowledge caused by the AR tool.

11.8 Concluding Remarks

This thesis has contributed to the literature that details the potential benefits mobile AR systems can bring to science-based subjects.

Sixth form and undergraduate MPharm students' knowledge did not improve after using the Pharma Compounds AR tool. As a result, no significant difference was identified; largely attributed to small sample sizes. Nevertheless, participants reported that using the tool improved their perceived knowledge and contributed to a better understanding of phenomena and concepts. It was also reported that using the AR tool improved learners' perceived visualisation skills as they were granted alternative perspectives of 3D structures that would otherwise only be visible as 2D representations. In addition to reportedly improving visualisation skills, students described the AR tool as engaging and enjoyable.

A statistically significant finding from both sixth form ($p<0.05$) and undergraduate students ($p<0.05$) was the increase in self-reported intrinsic motivation towards learning with the use of the Pharma Compounds AR educational tool when compared to the self-reported motivation towards learning using conventional methods. There was also an increase in the self-reported value and usefulness towards learning with the AR tool compared to the value and usefulness placed on conventional learning methods such as physical models, comprehension exercises, diagrams or educational videos; this increase, however, was not statistically significant (again, largely due to low sample size). The motivation and value attributed to an educational tool in students' learning affect the level of engagement a learner demonstrates and is said to be constructed from behavioural, cognitive, and emotional domains. Motivation is associated with the behavioural domain, whereas the usefulness and value associated with learning can be found in the cognitive domain. Therefore, by improving the intrinsic motivation a learner has towards their education through the use of the Pharma Compounds AR tool and the high levels of value it is reported to hold, learners may experience higher course engagement and result in performance improvements.

Semi-structured interviews with students and tutors revealed that the Pharma Compounds AR tool could be integrated into sixth form biology/chemistry and undergraduate Pharmacy education. Analysis of participants' responses against the NPT framework indicated a high level of coherence and cognitive participation as participants understood the purpose of the educational tool and suggested how it could be used. There were indications of moderate collective action as sixth form students reported having participated in group activities that included the AR educational tool; undergraduate students did not report such experiences.

Finally, there was a moderate level of reflexive monitoring by students and tutors as they discussed the visualisation benefits associated with viewing 3D models. There were responses that indicated that although the current educational tool could be integrated into educational environments (according to the NPT framework), improvements could be made to the tool that would further improve the process. Tutors reported that to enhance the integration process, educational technologists and educators must work together to ensure that content and functionality match the requirements and demands of their teaching methods and their student's learning process.

Although the AR tool has shown promise, it can be said that improvements need to be made to ensure its successful integration and application in the educational domain in accordance with the NPT framework. In-app stability and educational content were the most frequent improvements suggestions by students. With more time and recourses, more complex and complicated 3D models and animations could be created and programmed into the AR tool – e.g. including anatomical structures, mechanism of actions for drug molecules or hormone receptor site cascades. Adding audio that describes the phenomena or concept presented on screen was also an improvement suggested by both tutors and students. As mentioned in section 11.4.2, this addition would increase the tool's accessibility to less abled learners. A key element of the Pharma Compounds AR systems was the ability to scan more than one card at a time in close proximity to each other to create a new target and, thus new 3D model. This functionality can be further explored to offer new dynamic educational activities that allow users to build unique models and animations (e.g., bringing together functional group cards to create new chemical models or scan a card that represents a medicine/drug at the same time as a card that represents a

medical condition to see what effect the drug has on that condition). The current version of the Pharma Compounds AR tool serves as a proof-of-concept system and a steady platform that can be built upon to form a robust and thorough educational tool.

12 Bibliography

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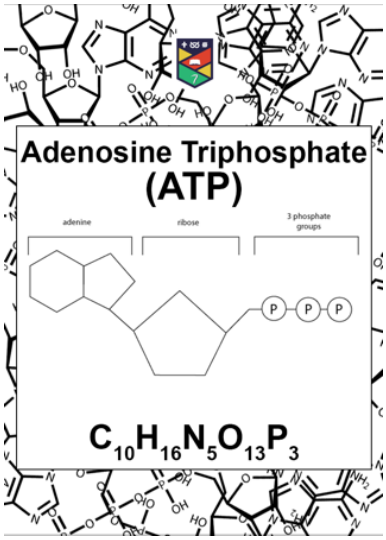
Appendix 1 – Pharma Compounds AR educational tool

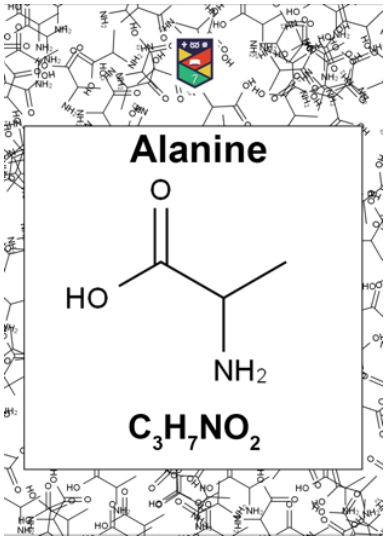
The Pharma Compounds AR education tool can be downloaded on to a smart phone or tablet via the links below or by searching 'Pharma Compounds' in the App store or Google Play store.

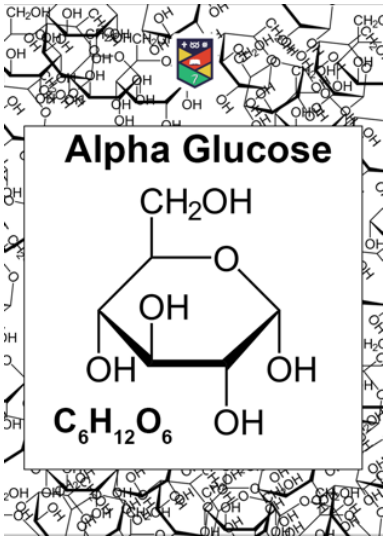
App Store:
https://apps.apple.com/gb/app/pharma-compounds/id1461494263

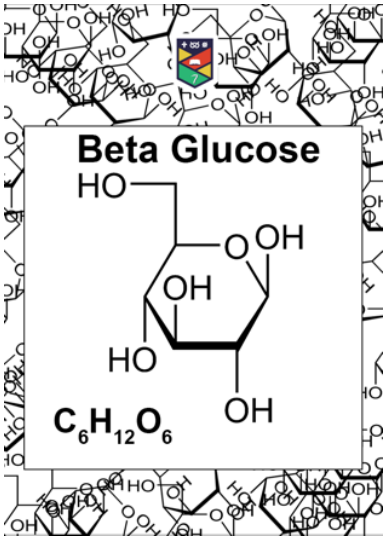
Google Play Store:
https://play.google.com/store/apps/details?id=com.keele.PharmaCompounds&hl=en_GB

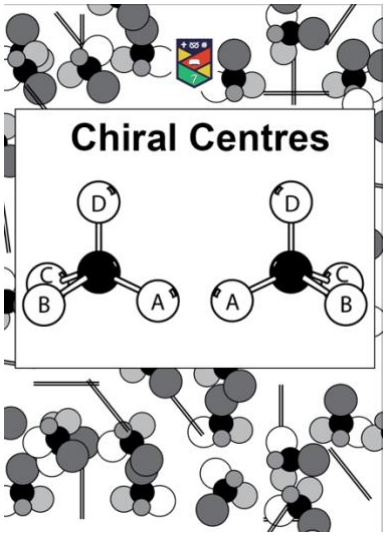
The app works with a set of 2D target image cards provided below. By scanning each card, you will be presented with a 3D model representation to the topic as well as supporting information. Certain cards become interactive when brought close together. For information on which cards have additional functions scan the cards and read the associated descriptions.

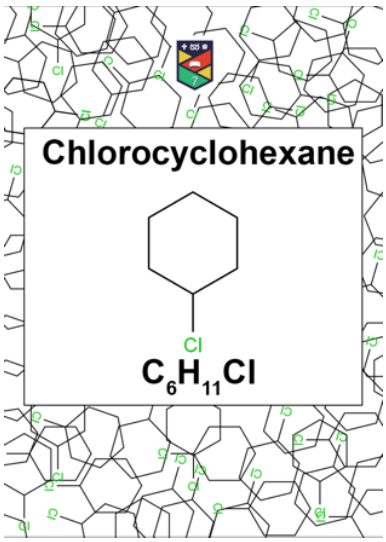

Adenosine Triphosphate
(ATP)
adenine
ribose
3 phosphate groups
P
P
P
$C_{10}H_{16}N_5O_{13}P_3$

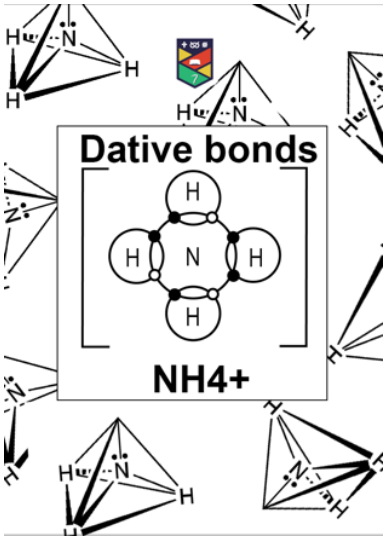

Alanine
O
HO
NH_2
$C_3H_7NO_2$

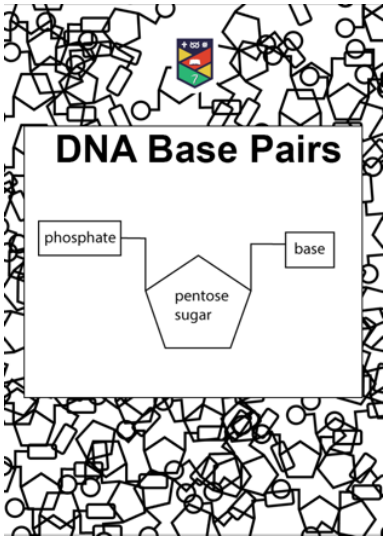

Alpha Glucose
CH_2OH
O
OH
OH
OH
OH
$C_6H_{12}O_6$

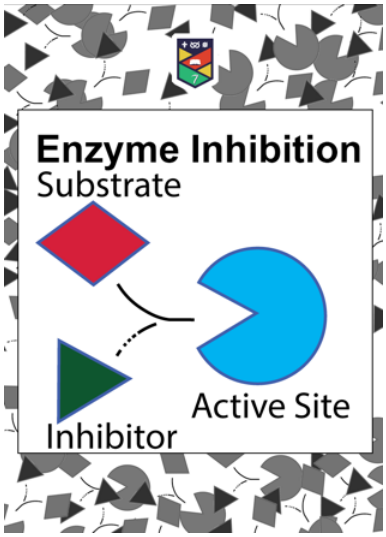

Beta Glucose
HO
O
OH
OH
HO
OH
$C_6H_{12}O_6$

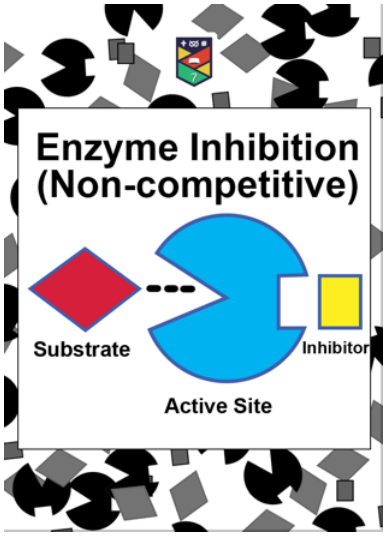

Chiral Centres
D
C
B
A
D
A
C
B

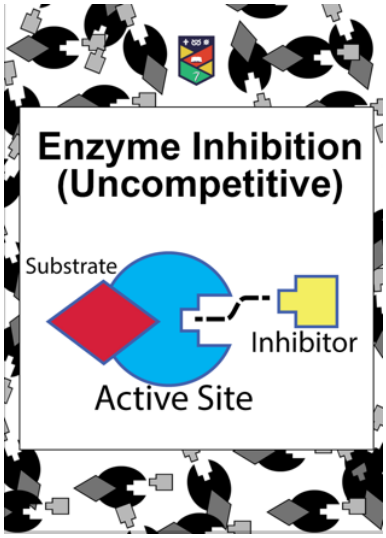

Chlorocyclohexane
Cl
$C_6H_{11}Cl$

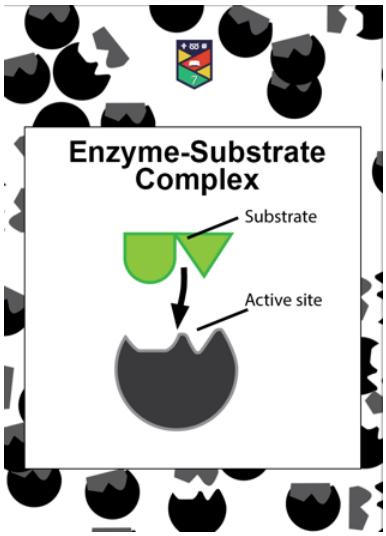

Dative bonds
H
H
N
H
H
NH4+

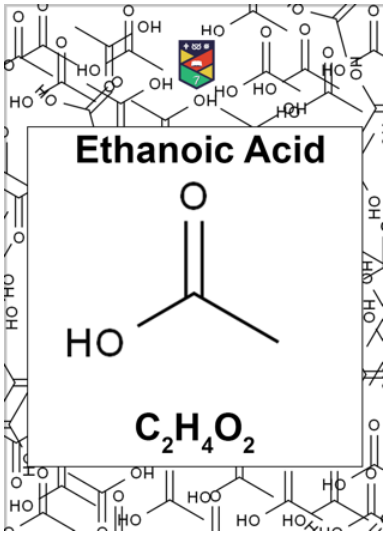

DNA Base Pairs
phosphate
base
pentose sugar

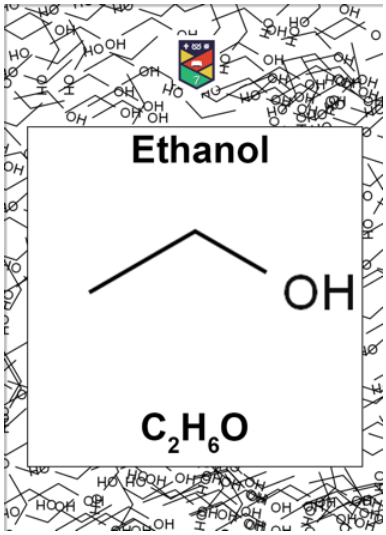

Enzyme Inhibition
Substrate
Active Site
Inhibitor

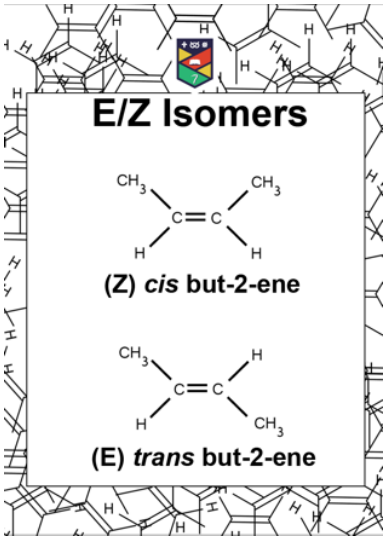

Enzyme Inhibition
(Non-competitive)
Substrate
Inhibitor
Active Site

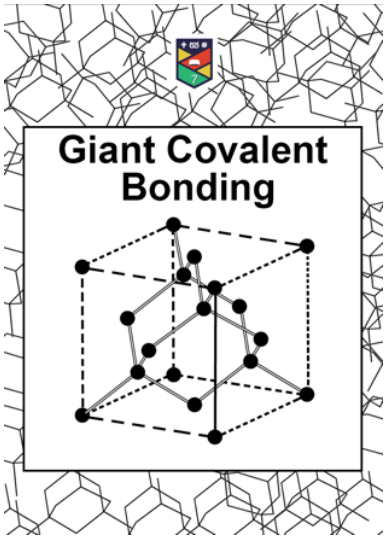

Enzyme Inhibition
(Uncompetitive)
Substrate
Inhibitor
Active Site

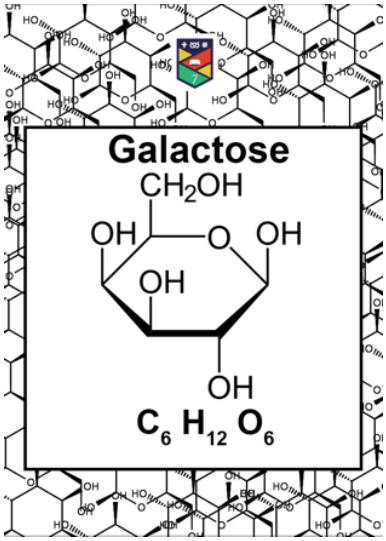

Enzyme-Substrate
Complex
Substrate
Active site

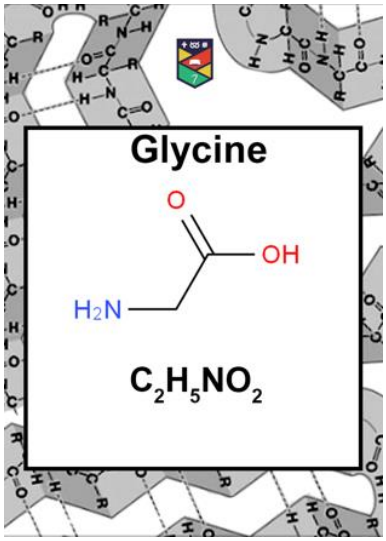

Ethanoic Acid
O
HO
$C_2H_4O_2$

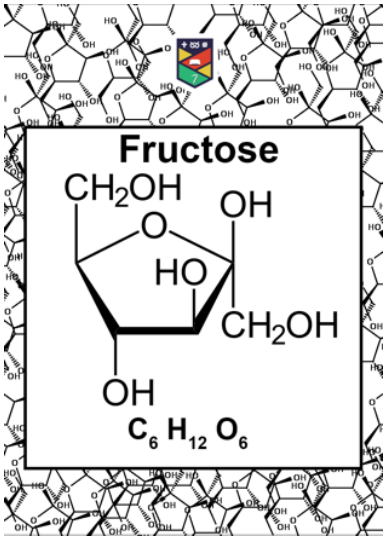

Ethanol
OH
C_2H_6O

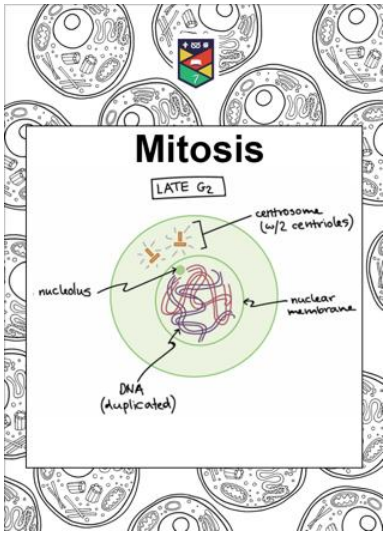

E/Z Isomers
(Z) *cis* but-2-ene
(E) *trans* but-2-ene

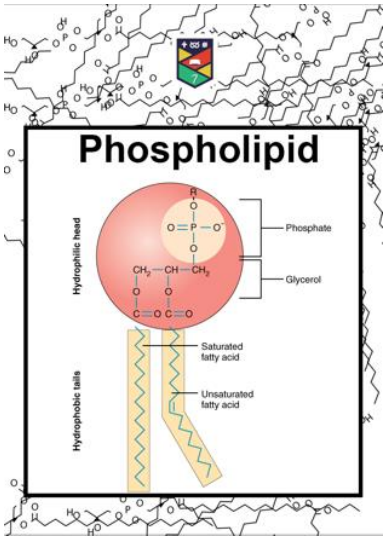

Giant Covalent Bonding

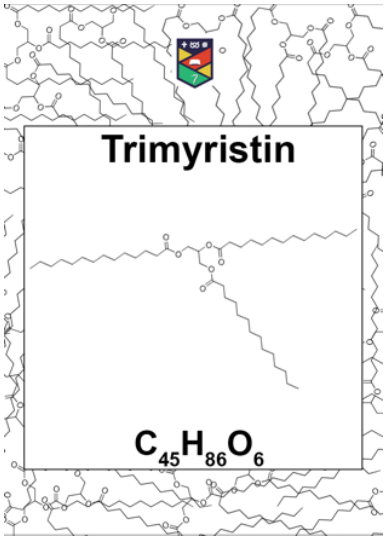

Galactose
CH_2OH
OH
OH
OH
OH
$C_6H_{12}O_6$

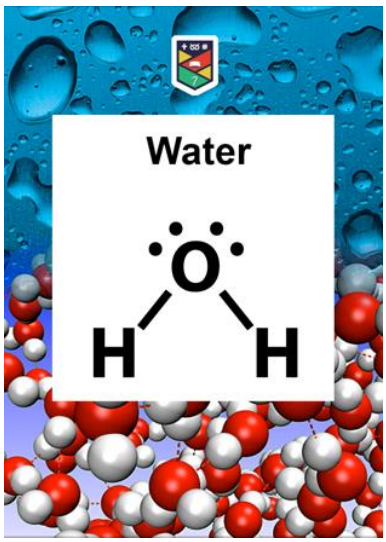

Glycine
O
OH
H_2N
$C_2H_5NO_2$

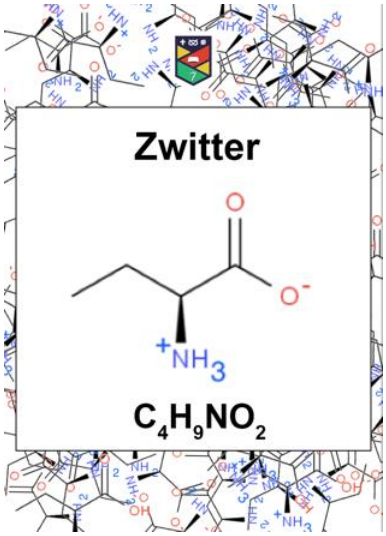

Fructose
CH_2OH
OH
O
HO
CH_2OH
OH
$C_6H_{12}O_6$


Mitosis
LATE G_2
centrosome
(w/2 centrioles)
nucleolus
nuclear
membrane
DNA
(duplicated)


Phospholipid
Hydrophilic head
Phosphate
Glycerol
Saturated
fatty acid
Unsaturated
fatty acid
Hydrophobic tails


Trimyristin
$C_{45}H_{86}O_6$


Water
O
H
H


Zwitter
O
O
$^+NH_3$
$C_4H_9NO_2$

Appendix 2 – Ethical approval letter for the development on the Pharma Compound AR tool

6th December 2018

Dear Deon,

PI: **Deon Essel**
Title: **Evaluating The Effectiveness of PharmaCARDs in Academic and Healthcare Education - Phase 1**
Ref: **ERP 3150**

Thank you for submitting Phase 1 of your application for review. The proposal was reviewed by the Panel Chair. I am pleased to inform you that Phase 1 of your application has been approved by the Ethics Review Panel.

If the fieldwork goes beyond the date stated in your application, or there are any amendments to your study you must submit an 'application to amend study' form to the ERP administrator at research.governance@keele.ac.uk. This form is available via https://www.keele.ac.uk/raise/researchsupport/projectassurance/researchethics/

If you have any queries please do not hesitate to contact me, in writing, via the ERP administrator, at research.governance@keele.ac.uk stating **ERP 3150** in the subject line of the e-mail.

Yours sincerely

pp C H Bannerman

Val Ball
Chair – Ethical Review Panel

Appendix 3 – Sixth form tutor and student letters of invitation for Pharma Compound AR tool developments

Dear Tutors,

RE: An Evaluation of AR PharmaCards in academic education

Thank you for committing to joining the study to evaluate the effect an augmented reality system has on academic science education. As discussed previously, before the main study can begin, Year 12 chemistry and biology teachers as well as Year 13 chemistry and biology students need to be surveyed to identify particular areas of the year 12 teaching material that was most difficult to learn and understand.

Below is a link to a participant information sheet and consent form for Year 12 chemistry and biology teachers that further explains the objectives of this particular part of the study and what they will be asked to do.

Participant information sheet, consent form and questionnaire:
https://goo.gl/forms/o15HTeqtufkhnKbf2

Following on from the information sheet and consent form, you will find a short questionnaire to that should take no more than 15 minutes to complete.

With regards to student participants, below is copy of an email inviting your Year 13 chemistry and biology students to also participate in the initial study for the development of the learning tool/revision aid (PharmaCards). To provide your students with further information they will find a participant information sheet and consent form attached through a link.

In addition, I would be extremely grateful if you would be so kind as to forward the email below to your year 13 chemistry and biology students.

Thank you very much, and if you have any questions, please do not hesitate to contact me on d.essel@keele.ac.uk.

Kind Regards

Deon Essel
Principal researcher
(14/11/18 v1.1)

Dear Student

RE: An Evaluation of AR PharmaCards in academic education

My name Is Deon Essel, I am a PhD student at Keele University currently carrying out a study into the use of augmented reality in academic education. Your 6th form has decided to be involved in this very unique study and hopes you will benefit from the opportunity.

At this moment in time, we at Keele University are developing a unique augmented reality learning/revision tool known as PharmaCard that has the ability to present 3D images on your view of the real world through a smartphone or tablet device. We hope that such a system will help to improve the learning experience for chemistry and biology students. In order to make the system as effective as possible we would like your help. If you decide to join the study, you will be asked to compete a short questionnaire that will gather information on what parts of your year 12 chemistry/biology course(s) you found difficult to visualise and understand.

Now talk of "augmented reality" and "research" may sound complicated, and because of that I have provided you with a web link that will take you to an online participant information sheet. Here you will find a lot more information explaining what we are trying to do and how you can be involved. If you would like to join us there is an online consent form that follows on from the information sheet.

Participant Information, consent form and questionnaire:
https://goo.gl/forms/3e1O0eEjOgM1bbqh2

Following on from the information sheet and consent form, you will find the questionnaire that should take no more than 15 minutes to complete.

If your parents would like some information on the study, below you will find an information sheet they can read that contains details of the study.

Parent participant information: https://goo.gl/forms/kSGMPUSB1nWLNh453

Thank you for your time and if you have any questions, please do not hesitate to contact me on d.essel@keele.ac.uk.

Kind regards

Deon Essel
Principal researcher

(14/11/18 v1.1)

Appendix 4 – Undergraduate tutor letter of invitation for Pharma Compound AR tool developments

Dear Tutor,

RE: An evaluation of AR PharmaCards in academic education

My name is Deon Essel, and I am a PhD student under the supervision of Prof Stephen Chapman and Dr Jessica Thompson. Currently, I am researching the use of augmented reality in education and my project will evaluate the use of an augmented reality teaching tool/revision aid in academic education. The study plans to use uniquely designed PharmaCards as the intervention tool. The cards have the ability to display 3D images on mobile devices as though they appear in the real world. The content of these cards will focus on stage 2 lecture material that is considered to be difficult for students to understand and learn.

In order to create the PharmaCards, I will distribute a questionnaire to all Stage 3 pharmacy and pharmaceutical science students to gather information on particular aspects of Stage 2 teaching material that they found particularly difficult to learn and understand. In addition, I hope to gain an alternate perspective through surveying lectures who teach the Stage 2 students. I would be extremely grateful if you would participate by answering a short questionnaire that should take no longer than 15 minutes to complete. Below I have attached a link to a participant information sheet and consent form, once completed you will be directed to the questionnaire.

Participant information, consent form and questionnaire:
https://goo.gl/forms/Sf5BELRYZF1JhFN72

Thank you and if you have any questions, please do not hesitate to contact me on d.essel@keele.ac.uk.

Kind regards

Deon Essel
Principal researcher
(14/11/18 v1.1)

Appendix 5 – Undergraduate student letter of invitation for Pharma Compound AR tool developments

Dear Stage 3 Students,

RE: An evaluation of AR PharmaCards in academic education

My name is Deon Essel, and I am a PhD student under the supervision of Prof Stephen Chapman and Dr Jessica Thompson. Currently, I am researching the use of augmented reality in education and my project will evaluate the use of an augmented reality teaching tool/revision aid in academic education. The study plans to use uniquely designed PharmaCards as the intervention tool. The cards have the ability to display 3D images on mobile devices as though they appear in the real world. The content of these cards will focus on Stage 2 lecture material that is considered to be difficult for students to understand and learn.

Some of you may have already seen, or in-fact used the 3D learning tool. In order to improve the tool and give it a wider scope, we require your help. If you decide to join the study, you will be asked to compete a short questionnaire that will gather information on what parts of stage 2 you found particularly difficult to visualise and understand.

Below is a link that will direct you to an online participant information sheet and consent form that will further explain the objectives of the study and what you will be required to do should you choose to join.

Participant information sheet, consent form and questionnaire:
https://goo.gl/forms/IcyndEJNaqk7zqdX2

Thank you for your time and if you have any questions, please do not hesitate to contact me on d.essel@keele.ac.uk.

Kind regards

Deon Essel
Principal researcher

(14/11/18 v1.1)

Appendix 6 – Year 12 tutor Pharma Compound design participant information sheet

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

PharmaCard Content Information Sheet: Year 12 Biology and Chemistry Teachers

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) system in academic education. This study will involve the use of unique AR playing cards, developed by Keele University. These cards are intended to be used as a learning aid or revision tool for 6th form chemistry and biology students. In order to ensure the content of these playing cards are appropriate, we would like help from you, your colleagues, and your students. These cards focus on specific aspects of year 12 chemistry and biology courses that are known and believed to be difficult to understand and learn. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study, as you currently teach year 12 student chemistry or biology. Your colleagues who also teach year 12 chemistry and biology as well as their students at your school have also been selected to join the study with additional participants recruited from other schools in the United Kingdom, Kenya, and Hong Kong.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here. As this study is fully anonymised you will not be able to withdraw from the study as any responses you submit will not be able to be linked back to yourself.

What will happen if I take part?

If you decide to take part you will be invited to complete a short online questionnaire that will follow on directly from the consent form. The questions are designed to identify specific topics and components of your year 12 biology or chemistry classes that you know or believe your students struggle to understand or visualise. The information you provide will be used to find the most common themes and topic areas where most difficulty is found and contribute to content for unique AR PharmaCards for you and your students to use.

What are the benefits of taking part?

By being involved in this study you will be contributing to the development of an advanced educational tool that is not widely available in schools. You will have the opportunity to use these unique cards either in teaching sessions or to distribute to your students for use at

home as revision tools that will hopefully improve their understanding.

What are the risks of taking part?
There are no tangible risks associated with your involvement in this study.

How will information about me be used?
The data collected from you will form part of a larger research project looking at how effective an augmented reality learning tool/teaching aid can be in academic education. Your responses to the questionnaire will not be passed on for use by third parties. Quotes may be taken from your responses and used in reports or publications generated by the study. Participants will not be identifiable from quotes taken from responses as the survey is anonymised.

Who will have access to information about me?
As this study is completely anonymous no personally identifiable information will be collected. However, should any information be provided by yourself in response to a question in the questionnaire, they will be kept strictly confidential and no one outside the project will have to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy data is not expected to be produced as all documents and responses from yourself will be submitted online. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as the study is anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371
(14/11/18 v1.1)

Appendix 7 – Year 13 student Pharma Compound design participant information sheet

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

PharmaCard Content Information Sheet - Year 13 Biology and Chemistry Students

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) system in academic education. This study will involve the use of unique AR playing cards, developed by Keele University. These cards are intended to be used as a learning aid or revision tool for 6th form chemistry and biology students. In order to ensure the content of these playing cards are appropriate, we would like help from you, your classmates, and your teachers. These cards focus on specific aspects of year 12 chemistry and biology courses that are known and believed to be difficult to understand and learn. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study, as you are currently a year 13 student studying chemistry or biology and aged 16 years or older. Your entire cohort (who study chemistry and biology) at your school have also been selected to join the study with participants recruited from other schools in the United Kingdom, Kenya, and Hong Kong.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here. As this study is fully anonymised you will not be able to withdraw from the study as any responses you submit will not be able to be linked back to yourself.

What will happen if I take part?

If you decide to take part, you will be invited to complete a short online questionnaire that will follow on directly from the consent form. The questions are designed to identify specific topics and components of your year 12 biology or chemistry classes that you know or believe you or your classmates struggled to understand or visualise. The information you provide will be used to find the most common themes and topic areas where most difficulty is found and contribute to content for unique AR PharmaCards that you and your colleagues can use.

What are the benefits of taking part?

By being involved in this study you will be contributing to the development of an advanced educational tool that is not widely available in schools. You may get access to this tool that may help improve your understanding.

What are the risks of taking part?
There are no tangible risks associated with your involvement in this study.

How will information about me be used?
The data collected from you will form part of a larger research project looking at how effective an augmented reality learning tool/teaching aid can be in academic education. Your responses from the questionnaires will not be passed on for use by third parties. Quotes may be taken from your responses and used in reports or publications generated by the study. Participants will not be identifiable from quotes taken from responses as the survey is anonymous.

Who will have access to information about me?
As this study is completely anonymous no personally identifiable information will be collected. However, should any information be provided by yourself in response to a question in the questionnaire, they will be kept strictly confidential and no one outside the project will have to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy data is not expected to be produced as all documents and responses from yourself will be submitted online. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as the study is anonymous.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk

Tel: 01782 733371
14/11/18 v1.1

Appendix 8 – Guardian of year 13 student Pharma Compound design participant information sheet

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

PharmaCard Content Information Sheet - Parents of Year 13 Biology and Chemistry Students

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) system in academic education. This study will involve the use of unique AR playing cards, developed by Keele University. These cards are intended to be used as a learning aid or revision tool for 6th form chemistry and biology students. In order to ensure the content of these playing cards are appropriate, we would like help from your child, their classmates, and their teachers. These cards focus on specific aspects of year 12 chemistry and biology courses that are known and believed to be difficult to understand and learn. Before you and your child decide whether or not to take part, it is important for you both to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with your child. Ask us if there is anything that is unclear or if you would like more information.

Why has your child been invited?

Your child has been chosen to join this study, as they are currently a year 13 student studying chemistry or biology and aged 16 years or older. Their entire cohort (who study chemistry and biology) at school have also been selected to join the study with participants recruited from other schools in the United Kingdom, Kenya, and Hong Kong.

Do they have to take part?

They are free to decide whether or not they wish to take part. If they do decide to take part, they will be asked to confirm their consent through an online consent form that follows on from their on participant information sheet. As this study is fully anonymised, they will not be able to withdraw from the study as any responses they submit will not be able to be linked back to themselves.

What will happen if they take part?

If they decide to take part, they will be invited to complete a short online questionnaire that follows on directly from their consent form. The questions are designed to identify specific topics and components of their year 12 biology or chemistry classes that they know or believe they or their classmates struggled to understand or visualise. The information they provide will be used to find the most common themes and topic areas where most difficulty is found and contribute to content for unique AR PharmaCards that they and their colleagues can use.

What are the benefits of taking part?
By being involved in this study they will be contributing to the development of an advanced educational tool that is not widely available in schools. They may get access to this tool that will hopefully improve their understanding.

What are the risks of taking part?
There are no tangible risks associated with their involvement in this study.

How will information about your child be used?
The data collected from your child will form part of a larger research project looking at how effective an augmented reality learning tool/teaching aid can be in academic education. Their responses from the questionnaires will not be passed on for use by third parties. Quotes may be taken from their responses and used in reports or publications generated by the study. Participants will not be identifiable from quotes taken from responses as the survey is anonymous.

Who will have access to information about your child?
As this study is completely anonymous no personally identifiable information will be collected. However, should any information be provided by your child in response to a question in the questionnaire, they will be kept strictly confidential and no one outside the project will have to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy data is not expected to be produced as all documents and responses from your child will be submitted online. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your child's responses may be used in future publications and reports however they will not be identifiable as the study is anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
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E-mail: research.governance@keele.ac.uk
Tel: 01782 733371
(14/11/18 v1.1)

Appendix 9 – Stage 2 tutor Pharma Compound design participant information sheet

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

PharmaCard Content Information Sheet: Stage 2 MPharm and Pharmaceutical Science Lecturers

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) system in academic education. This study will involve the use of unique AR playing cards, developed by Keele University. These cards are intended to be used as a learning aid or revision tool for stage 2 undergraduate pharmacy and pharmaceutical science students - if proved to be useful, we hope additional cards can be developed for other year groups. In order to ensure the content of these playing cards are appropriate, we would like help from you, your colleagues and your students. These cards focus on specific aspects of the stage 2 MPharm and Pharmaceutical Science course that are known and believed to be difficult to understand and learn. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study, as you currently teach Stage 2 MPharm and Pharmaceutical science students. Your colleagues who also teach Stage 2 MPharm and Pharmaceutical science students at Keele school of pharmacy have also been selected to join the study along with stage 3 students.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part you will be asked to confirm your consent through an online consent form that follows on from here. As this study is fully anonymised you will not be able to withdraw from the study as any responses you submit will not be able to be linked back to yourself.

What will happen if I take part?

If you decide to take part you will be invited to complete a short online questionnaire that will follow on directly from the consent form. The questions are designed to identify specific topics and components of Stage 2 on the MPharm and Pharmaceutical science courses that you know or believe your students struggle to understand. The information you provide will be used to find the most common areas and topics of the courses that most difficulty is found, and this information will contribute to the content of unique augmented reality PharmaCARDs for you and your students to use.

What are the benefits of taking part?

By being involved in this study you will be contributing to the development of an advanced educational tool that is not widely available at any level of education. You will have the opportunity to use these unique cards either in teaching sessions or to distribute to your students for use at home as revision tools that will hopefully improve their understanding.

What are the risks of taking part?
There are no tangible risks associated with your involvement in this study. However some participants are known to the principal researcher and as a result so it may be possible to partially identify you from your responses.

How will information about me be used?
The data collected from you will form part of a larger research project looking at how effective an augmented reality learning tool/teaching aid can be in academic education. Your responses to the questionnaire will not be passed on for use by third parties. Quotes may be taken from your responses and used in reports or publications generated by the study. Participants will not be identifiable from quotes taken from responses as the survey is anonymised.

Who will have access to information about me?
As this study is completely anonymous no personally identifiable information will be collected. However, should any information be provided by yourself in response to a question in the questionnaire, they will be kept strictly confidential and no one outside the project will have to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy data is not expected to be produced as all documents and responses from yourself will be submitted online. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as the study is anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University

Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371
(14/11/18 v1.1)

Appendix 10 – Stage 3 student Pharma Compound design participant information sheet

PharmaCard Content Information Sheet - Stage 3 MPharm and Pharmaceutical science Students

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) system in both academic education. This study will involve the use of unique AR playing cards, developed by Keele University. These cards are intended to be used as a learning aid or revision tool for stage 2 undergraduate pharmacy students - if proved to be useful, we hope additional cards can be developed for other year groups. In order to ensure the content of these playing cards are appropriate, we would like input from you, your colleagues, and your lecturers. These cards focus on specific aspects of the stage 2 MPharm and Pharmaceutical Science course that are known and believed to be difficult to understand and learn. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study as you are currently in the third year of either a Pharmacy or Pharmaceutical science degree at Keele University. Your entire cohort at Keele University has also been selected to join the study.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here. As this study is fully anonymised you will not be able to withdraw from the study as any responses you submit will not be able to be linked back to yourself.

What will happen if I take part?

If you decide to take part, you will be invited to complete a short online questionnaire that that will follow on directly from the consent form. The questions are designed to identify specific topics and components of the second year of the MPharm and Pharmaceutical Science course that you know or believe you or your classmates struggled to understand. The information you provide will be used to find the most common areas and topics of the courses that most difficulty is found, and this information will contribute to the content of unique augmented reality PharmaCards for you and your colleagues to use.

What are the benefits of taking part?

By being involved in this study you will be contributing to the development of an advanced educational tool that is not widely available in schools. You may get access to this tool that will hopefully improve your understanding.

What are the risks of taking part?
There are no tangible risks associated with your involvement in this study. However, some participants are known to the principal researcher so it may be possible to partially identify you from your responses.

How will information about me be used?
The data collected from you will form part of a larger research project looking at how effective an augmented reality learning tool/teaching aid can be in academic education. Your responses form the questionnaires will not be passed on for use by third parties. Quotes may be taken from your responses and used in reports or publications generated by the study. Participants will not be identifiable from quotes taken from responses as the survey is anonymised.

Who will have access to information about me?
As this study is completely anonymous no personally identifiable information will be collected. However, should any information be provided by yourself in response to a question in the questionnaire, they will be kept strictly confidential and no one outside the project will have to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy data is not expected to be produced as all documents and responses from yourself will be submitted online. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as the study is anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371
(14/11/18 v1.1)

Appendix 11 – Year 12 tutor Pharma Compounds design consent form

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Consent Form – Year 12 Teachers

1. I confirm that I have read and understood the information sheet (dated 14/11/18 v1.1) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am unable to withdraw from the study as it is fully anonymised

3. I understand that the collection of data is anonymous, and that the data will be used to produce reports or publications

4. I agree for my responses to be used as quotes in any reports or publications, and that I will not be directly identifiable from said quotes

I agree to join the study

☐ I agree

(29/11/18 v1.2)

Appendix 12 – Year 13 student Pharma Compound design consent form

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Consent Form – Year 13 Students

1. I confirm that I have read and understood the information sheet (dated 14/11/18 v1.1) for the above study and have had the opportunity to ask questions.

2. I confirm that I am at least 16 years old.

3. I understand that my participation is voluntary and that I am unable to withdraw from the study as it is fully anonymised

4. I understand that the collection of data is anonymous, and that the data will be used to produce reports or publications

5. I agree for my responses to be used as quotes in any reports or publications, and that I will not be directly identifiable from said quotes

I agree to join the study
☐ I agree

☐ I agree for my child to join the study

(29/11/18 v1.2)

Appendix 13 – Stage 2 tutor Pharma Compounds design consent form

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Consent Form – Stage 2 MPharm tutors

1. I confirm that I have read and understood the information sheet (dated 14/11/18 v1.1) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am unable to withdraw from the study as it is fully anonymised

3. I understand that the collection of data is anonymous, and that the data will be used to produce reports or publications

4. I agree for my responses to be used as quotes in any reports or publications, and that I will not be directly identifiable from said quotes

I agree to join the study

☐ I agree

(29/11/18 v1.2)

Appendix 14 – Stage 2 tutor Pharma Compounds design consent form

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Consent Form – Stage 3 MPharm student

1. I confirm that I have read and understood the information sheet (dated 14/11/18 v1.1) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am unable to withdraw from the study as it is fully anonymised

3. I understand that the collection of data is anonymous, and that the data will be used to produce reports or publications

4. I agree for my responses to be used as quotes in any reports or publications, and that I will not be directly identifiable from said quotes

I agree to join the study

☐ I agree

(29/11/18 v1.2)

Appendix 15 – Year 12 tutor Pharma Compound design questionnaire

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Year 12 Teachers PharmaCard Content Collection

What subject do you teach?

☐ Biology
☐ Chemistry
☐ Both

In what country do you teach?

☐ United Kingdom
☐ Hong Kong
☐ Kenya

What examination board/syllabus does your chemistry/biology course follow?

What 5 topics do you think students find most difficult and can you rank them from most to least difficult?

On a scale of 1 to 5 how difficult do you think students find the most difficult topic?

Very easy				Very difficult
1	2	3	4	5

Why do you think students find these topics more difficult than the others?

Do you feel the difficulty is a result of students struggling to visualise certain structures, objects and/or processes?

☐ Yes
☐ No

If yes, what specific structures, objects or processes do you think they struggle to visualise?

Can you think of any structures, objects and/or processes that you feel new chemistry/biology students would struggle to picture?

Do you think having an interactive 3D tool that displays structures, objects and processes would help your students better understand these topic areas?

☐ Yes
☐ No

(14/11/18 v1.1)

Appendix 16 – Year 13 student Pharma Compound design questionnaire

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Year 13 Students PharmaCARD Content Collection

What gender do you mostly identity with?
☐ Male
☐ Female
☐ Prefer not to say

What age group do you belong to?
☐ 16 - 17 years
☐ 18 - 19 years
☐ 19+ years

In what country do you study?
☐ United Kingdom
☐ Hong Kong
☐ Kenya

What course are you currently enrolled on?
☐ Biology only
☐ Chemistry only
☐ Biology and Chemistry

What examination board/syllabus does your chemistry/biology course follow?

Can you think of the top 5 most difficult chemistry/biology topics that you covered during year 12 and rank them from most to least difficult?

On a scale of 1 to 5 how difficult do you think students find the most difficult topic?

Very easy				Very difficult
1	2	3	4	5

Select an option from below, you believe to be the main reason behind the difficulty of the topics

☐ Low interest in the topic
☐ Complexity of the topic
☐ Visualising/picturing the learning material

Can you think of any other reason why these topics were the most difficult to learn/understand?

What structures, objects and/or processes did you struggle to picture during your year 12 chemistry/biology studies?

Can you think of any other structures, objects and/or processes that you feel new year 12 chemistry/biology students would struggle to picture?

Do you think having an interactive 3D tool that displays structures, objects and processes would help you better understand these topic areas?

☐ Yes
☐ No

(14/11/18 v1.1)

Appendix 17 – Stage 2 tutor Pharma Compound design questionnaire

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Stage 2 MPharm and Pharmaceutical Science Lecturers PharmaCard Content Collection

What 5 topics do you think students find most difficult and can you rank them from most to least difficult?

On a scale of 1 to 5 how difficult do you think students find the most difficult topic?

Very easy				Very difficult
1	2	3	4	5

Why do you think students find these topics more difficult than the others?

Do you feel the difficulty is a result of students struggling to visualise certain structures, objects and/or processes?

☐ Yes
☐ No

If Yes, what specific structures, objects, or processes do you think they struggle to visualise?

Can you think of any other structures, objects, and/or processes you know or believe students struggle to visualise?

Do you think having an interactive 3D tool that displays structures, objects and processes would help your students better understand these topic areas?

(14/11/18 v1.1)

Appendix 18 – Stage 3 student Pharma Compound design questionnaire

An Evaluation of Augmented Reality PharmaCARDs in Academic Education

Stage 3 MPharm and Pharmaceutical Science Students
PharmaCard Content Collection

What gender do you most identify with?
☐ Male
☐ Female
☐ Prefer not to say

What age group do you belong to?
☐ 19 - 21 years
☐ 22 - 25 years
☐ 25+ years

Are you enrolled as an international or a domestic student?
☐ International student
☐ Domestic student

Can you think of the top 5 most difficult topics you covered during Stage 2 and rank them from most to least difficult?

On a scale of 1 to 5 how difficult do you think students find the most difficult topic?

Very easy				Very difficult
1	2	3	4	5

Select an option from below, you believe to be the main reason behind the difficulty of the topics
☐ Low interest in the topic
☐ Complexity of the topic
☐ Visualising/picturing the learning material

Can you think of any other reason why these topics were the most difficult to learn/understand?

What structures, objects and/or processes did you struggled to picture during Stage 2 of your MPharm or Pharmaceutical science degree?

Can you think of any other structures, objects and/or processes that you feel new stage 2 students would struggle to picture?

Do you think having an interactive 3D tool that displays structures, objects and processes would help you better understand these topic areas?

☐ Yes
☐ No

(14/11/18 v1.1)

Appendix 19 – Ethical approval letter for sixth form participation in main study

18 December 2018

Dear Deon,

PI: **Deon Essel**
Title: **Evaluating The Effectiveness of PharmaCARDs in Academic and Healthcare Education – Phase 2**
Ref: **ERP3150**

Thank you for submitting Phase 2 of your application for review. The proposal was reviewed by the Panel Chair. I am pleased to inform you that Phase 2 of your application has been approved by the Ethics Review Panel.

If the fieldwork goes beyond the date stated in your application, or there are any amendments to your study you must submit an 'application to amend study' form to the ERP administrator at research.governance@keele.ac.uk. This form is available via https://www.keele.ac.uk/raise/researchsupport/projectassurance/researchethics/

If you have any queries please do not hesitate to contact me, in writing, via the ERP administrator, at research.governance@keele.ac.uk stating **ERP3150** in the subject line of the e-mail.

Yours sincerely

pp C H Bonnerman

Val Ball
Chair – Ethical Review Panel

Appendix 20 – Ethical approval letter for undergraduate MPharm participation in main study

18 December 2018

Dear Deon,

PI: **Deon Essel**
Title: **Evaluating The Effectiveness of PharmaCARDs in Academic and Healthcare Education – Phase 3**
Ref: **ERP3150**

Thank you for submitting Phase 3 of your application for review. The proposal was reviewed by the Panel Chair. I am pleased to inform you that Phase 3 of your application has been approved by the Ethics Review Panel.

If the fieldwork goes beyond the date stated in your application, or there are any amendments to your study you must submit an 'application to amend study' form to the ERP administrator at research.governance@keele.ac.uk. This form is available via https://www.keele.ac.uk/raise/researchsupport/projectassurance/researchethics/

If you have any queries please do not hesitate to contact me, in writing, via the ERP administrator, at research.governance@keele.ac.uk stating **ERP3150** in the subject line of the e-mail.

Yours sincerely

pp C H Bonnerman

Val Ball
Chair – Ethical Review Panel

Appendix 21 – Ethical approval letter for students and tutor interviews

Keele University FMHS Faculty Research Ethics Committee
health.ethics@keele.ac.uk

Keele UNIVERSITY

4th August 2020

Dear Deon

Project Title:	Evaluating the Effectiveness of PharmaCompound Cards in Academic and Healthcare Education
REC Project Reference:	MH-200133
Type of Application	Amendment

Keele University's Faculty of Medicine and Health Sciences Research Ethics Committee (FMHS FREC) reviewed the above amendment.

Favourable Ethical opinion
The members of the Committee gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Reporting requirements
The University's standard operating procedures give detailed guidance on reporting requirements for studies with a favourable opinion including:

- Notifying substantial amendments
- Notifying issues which may have an impact upon ethical opinion of the study
- Progress reports
- Notifying the end of the study

Approved documents
The documents reviewed and approved are:

Document	Version	Date
All documents submitted with MH-200133		

Yours sincerely,

Dr Simon White

Chair

Appendix 22 – Sixth form letter of invitation for main study

Dear Tutors,

Thank you once again for your patience and willingness for your year 12 students' involvement in this study. I can confirm that the information provided by both year 13 students and yourself have contributed to the development of augmented reality PharmaCards that will be used in the next phase of the research project and at this moment in time, those cards are in development.

In preparation for the next step, I will begin recruiting year 12 and Biology and Chemistry students, with whom the main study will involve. Students will be invited to complete a series of questionnaires and quizzes either side of using the PharmaCards as a learning/revision tool. Below is an email inviting your year 12 Biology and Chemistry students to join the study. The email also contains links to an information sheet for both students and their parents further detailing the requirements of the study. I would be extremely grateful if you are able to forward the email on to your year 12 Biology and Chemistry students at your Sixth Form.

Thank you very much for your help, and if you have any questions, please do not hesitate to contact me.

Kind Regards

Deon Essel
Principal researcher

(20/11/2018, v1.2)

Dear Student,

My name Is Deon Essel, I am a PhD student at Keele University currently carrying out a study into the use of augmented reality in academic education. We at Keele University have developed a unique augmented reality (AR) learning/revision tool known as PharmaCard. This educational tool has the ability to present 3D images on your view of the real world via a smartphone or tablet device. We hope that such a system will help to improve the learning experience for both chemistry and biology students.

With the help of your colleagues and teachers, we have put together a series of unique AR PharmaCards for your use as year 12 Biology or Chemistry students. In order to find out how useful these cards may be we would like your involvement in a research project that will evaluate exactly how useful the PharmaCards are as a learning/revision tool. If you decide to join the study, you will be invited to complete a series of pre- and post-questionnaires and quizzes in addition to being given access

to the AR PharmaCard system. Once completed you will be invited to a group discussion with fellow students to discuss your opinions on how beneficial you found PharmaCards.

Now talk of “augmented reality” and “research” may sound complicated, and because of that I have provided you with a web link that will take you to an online participant information sheet. Here you will find a lot more information explaining what we are trying to do and how you can be involved. If you would like to join us there is an online consent form that follows on from the information sheet.

Participant information sheet, consent form & pre-questionnaire:
https://goo.gl/forms/cDzWyonXcOuAHZTG2

Following on from the information sheet and consent form, you will find the pre-questionnaire that should take you no more than 15 minutes to complete.

If your parents would like some information on the study, below you will find an information sheet that contains details of the study.

Parent participant information sheet:
https://goo.gl/forms/nAFVZmLN5c5tNJeG2

Thank you for your time and if you have any questions, please do not hesitate to contact me.

Kind regards

Deon Essel
Principal researcher

(20/11/18 v1.2)

Appendix 23 – MPharm letter of invitation for main study

Dear Student,

My name Is Deon Essel, I am a PhD student at Keele University My PhD project will evaluate the use of augmented reality in academic education.

My name Is Deon Essel, I am a PhD student at Keele University under the supervision of Professor Stephen Chapman and Dr Jessica Thompson. My research project will evaluate the use of an augmented reality in academic education. We at Keele University have developed a unique augmented reality (AR) learning/revision tool known as PharmaCard. This educational tool has the ability to present 3D images on your view of the real world via a smartphone or tablet device. We hope that such a system will help to improve the learning experience both in your learning and revision sessions.

With the help of your colleagues in stage 3 and your lecturers, we have put together a series of unique AR PharmaCards for your use. In order to find out how useful these cards maybe we would like your involvement in a research project that will evaluate exactly how useful the PharmaCards are as a learning/revision tool. If you decide to join the study, you will be invited to complete a series of pre- and post-questionnaires and quizzes in addition to being given access to the AR PharmaCard system. Once completed, you will be invited to a group discussion with fellow students to discuss your opinions on how beneficial you found PharmaCards.

Below is a link to a participant information sheet where you will find more information of what the project involves. If you would like to join us there is an online consent form that follows on from the information sheet.

Participant information sheet, consent form & pre-questionnaire:
https://goo.gl/forms/5WOJ2AbgTxYGTkJr2

Following on from the information sheet and consent form, you will find the pre-questionnaire that should take you no more than 15 minutes to complete.

Thank you for your time and I look forward to seeing you on the study.

Kind regards

Deon Essel
Principal researcher

(20/11/18 v1.2)

Appendix 24 – Sixth form main study participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Participant Information

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool in academic education. This study will involve the use of unique AR playing cards, developed by Keele University with help from your teachers and fellow students. The content of the cards include Biology and Chemistry topics that your older colleges and teachers have noted as being slightly more difficult to learn and understand. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study, as you are currently studying Biology and/or Chemistry in year 12. Your classmate who also study Biology and/or Chemistry in year 12 have also been invited to join the study with participants also recruited from other schools in the United Kingdom, Kenya, and Hong Kong.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here. Once you have joined the study you are free to withdraw without giving reasons up until 7 days after submitting the consent form. Data collected within those seven days will be removed.

What will happen if I take part?

If you decide to take part, you will be invited to complete a short pre-questionnaire that addresses your views and motivation towards your current learning and revision methods. You will then be asked to complete a pre-quiz so we can grasp your level of understanding of course material. Following the completion of the pre-questionnaire and quiz you will receive access to the AR PharmaCompounds mobile application and the playing cards to use as a learning/revision tool. Once you have had sufficient time to use the AR tool, you will be invited to complete a second quiz. The content of this quiz will be based of the content of the first quiz. This is to measure any changes in knowledge that could be attributed to the PharmaCompounds. A post-questionnaire, similar to the first, will follow. Both pre- and post-questionnaires have high similarity to enable you to re-assess your views, opinions and motivation towards learning while using the AR PharmaCompounds as a revision tool and learning aid. Finally, you will be invited to a focus group that will further explore your experiences and opinions on the use of the AR PharmaCompounds. Focus groups are best

described as group discussions where each member involved has the opportunity to voice their opinions on the discussed topic. Focus groups enable members to interact and influence each other during the discussion as well as consider each other's perspectives on the topic discussed.

Will I be recorded and how will the recorded media be used?
The focus groups dialogue will be digitally recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?
Your involvement in this study will enable you to have access to a new educational tool that, currently, is not widely available to at any level of education. By using this learning tool, you may improve your understanding.

What are the risks of taking part?
Each stage of the study requires participants to provide a consistent email address, making this a non-anonymous study. As a result, the principal researcher will be able to identify your specific responses and scores. The study has been intentional designed this way to enable a comparison between the data collected before and after the use of the PharmaCompounds as well as to track your progression through the study.

How will information about me be used?
The data collected will form part of larger project to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The email address provided will be used to forward the consecutive stages of this study for participants to complete. The email address will also be used as an indicator to track progression through the study. The data generated in the questionnaires, quizzes and focus groups will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about me?
Any personal information that has been collected about you during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy version of consent forms for focus groups will be collected and stored in locked cupboard that only my supervisory team and I have access to. No other hard copy data is expected to be produced as all other documents and responses from yourself will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?

The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371

20/11/2018 v1.2

Appendix 25 – Sixth form main study parent participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Information Sheet - Parents of Year 12 Biology and Chemistry Students

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool in academic education. This study will involve the use of unique AR playing cards, developed by Keele University with help from your child, their teachers, and fellow students. The content of the cards include Biology and Chemistry topics that your older colleges and teachers have noted as being slightly more difficult to learn and understand. Before your child decides whether or not they wish to take part, it is important for you both to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with your child if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have they been invited?

Your child has been chosen to join this study, as they are currently studying Biology and/or Chemistry in year 12. Their classmate who also study Biology and/or Chemistry in year 12 have also been invited to join the study with participants also recruited from other schools in the United Kingdom, Kenya, and Hong Kong.

Do they have to take part?

Your child is free to decide whether they wish to take part or not. If they do decide to take part, they will be asked to confirm their consent through an online consent form that follows on from their information sheet. Once they have joined the study, they are free to withdraw without giving reasons up until 7 days after submitting the consent form. Data collected within those seven days will be removed.

What will happen if they take part?

If your child decides to take part, they will be invited to complete a short pre-questionnaire that addresses their views and motivation towards their current learning and revision methods. They will then be asked to complete a pre-quiz so we can grasp their level of understanding of course material. Following the completion of the pre-questionnaire and quiz they will receive access to the AR PharmaCard mobile application and the playing cards to use as a learning/revision tool. Once they have had sufficient time to use the AR tool, they will be invited to complete a second quiz. The content of this quiz will be based of the content of the first quiz. This is to measure any changes in knowledge that could be attributed to the PharmaCards. A post-questionnaire, similar to the first, will follow. Both pre- and post-questionnaires have high similarity to enable your child to re-assess their views, opinions and motivation towards learning while using the AR PharmaCards as a revision tool and learning aid. Finally, they will be invited to a focus group that will further

explore their experiences and opinions on the use of the AR PharmaCards. Focus groups are best described as group discussions where each member involved has the opportunity to voice their opinions on the discussed topic. Focus groups enable members to interact and influence each other during the discussion as well as consider each other's perspectives on the topic.

Will my child be recorded and how will the recorded media be used?
The focus groups dialogue will be digitally recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your child's written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?
Your child's involvement in this study will enable them to have access to a new educational tool that, currently, is not widely available to at any level of education. By using this learning tool, they may improve their understanding.

What are the risks of taking part?
Each stage of the study requires participants to provide a consistent email address, making this a non-anonymous study. As a result, the principal researcher will be able to identify your child's specific responses and scores. The study has been intentional designed this way to enable a comparison between the data collected before and after the use of the PharmaCards.

How will information about my child be used?
The data collected will form part of larger project to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The email address provided will be used to forward the consecutive stages of this study for participants to complete. The email address will also be used as an indicator to track progression through the study. The data generated in the questionnaires, quizzes and focus groups will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about my child?
Any personal information that has been collected about your child during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy version of consent forms for focus groups will be collected and stored in locked cupboard that only my supervisory team and I have access to. No other hard copy data is expected to be produced as all other documents and responses from your child will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your child's responses may be used in future publications and reports however they will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371
20/11/2018 v1.2

Appendix 26 – MPharm main study participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Undergraduate Stage 2 Pharmacy and Pharmaceutical Science Students

Participant Information

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool in academic education. This study will involve the use of unique AR playing cards, developed by Keele University with help from your lecturers and fellow students. The content of the cards include stage 2 MPharm and Pharmaceutical Science topics that your older colleges and tutors have noted as being slightly more difficult to learn and understand. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been chosen to join this study, as you are currently in year two of either a Pharmacy or Pharmaceutical science degree at Keele University. Your entire cohort at Keele University has also been selected to join the study.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here. Once you have joined the study you are free to withdraw without giving reasons up until 7 days after submitting the consent form. Data collected within those seven days will be removed.

What will happen if I take part?

If you decide to take part, you will be invited to complete a short pre-questionnaire that addresses your views and motivation towards your current learning and revision methods. You will then be asked to complete a pre-quiz so we can grasp your level of understanding of course material. Following the completion of the pre-questionnaire and quiz you will receive access to the AR PharmaCard mobile application and the playing cards to use as a learning/revision tool. Once you have had sufficient time to use the AR tool, you will be invited to complete a second quiz. The content of this quiz will be based of the content of the first quiz. This is to measure any changes in knowledge that could be attributed to the PharmaCards. A post-questionnaire, similar to the first, will follow. Both pre- and post-questionnaires have high similarity to enable you to re-assess your views, opinions and motivation towards learning while using the AR PharmaCards as a revision tool and learning aid. Finally, you will be invited to a focus group that will further explore your experiences and opinions on the use of the AR PharmaCards. Focus groups are best described as group

discussions where each member involved has the opportunity to voice their opinions on the discussed topic. Focus groups enable members to interact and influence each other during the discussion as well as consider each other's perspectives on the topic discussed.

Will I be recorded and how will the recorded media be used?
The focus groups dialogue will be digitally recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?
Your involvement in this study will enable you to have access to a new educational tool that, currently, is not widely available to at any level of education. By using this learning tool, you may improve your understanding.

What are the risks of taking part?
Each stage of the study requires participants to provide a consistent email address, making this a non-anonymous study. As a result, the principal researcher will be able to identify your specific responses and scores. The study has been intentional designed this way to enable a comparison between the data collected before and after the use of the PharmaCards as well as to track your progression through the study.

How will information about me be used?
The data collected will form part of larger project to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The email address provided will be used to forward the consecutive stages of this study for participants to complete. The email address will also be used as an indicator to track progression through the study. The data generated in the questionnaires, quizzes and focus groups will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about me?
Any personal information that has been collected about you during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. Hard copy version of consent forms for focus groups will be collected and stored in locked cupboard that only my supervisory team and I have access to. No other hard copy data is expected to be produced as all other documents and responses from yourself will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371

20/11/2018 v1.2

Appendix 27 – Sixth form main study interview participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Sixth Form Student Interview Participant Information

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool in academic education. This study involves the use of unique AR playing cards, developed by Keele University with help from sixth form chemistry and biology students and their teachers. The content of the cards include Biology and Chemistry topics that their older colleges and teachers have noted as being slightly more difficult to learn and understand. Before you decide whether or not to take part in the interview, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been invited to an interview as you have had hands on experience using the Pharma Compounds augmented reality App.

Do I have to take part?

You are free to decide whether you wish to be interviewed. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here.

What will happen if I take part?

If you decide to take part, you will be asked to familiarise yourself with the AR learning tool before being invited to a short interview. You will be sent a weblink that will take you to a virtual interview room with the principal researcher. The interview should last no longer than 15 minutes.

Will I be recorded and how will the recorded media be used?

The interview audio will be recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?

Your involvement will help shape the development of this app and similar augmented reality tools for use in your future studies.

What are the risks of taking part?

There are minimal risks involved with the interviews in this study. You will be sent a web link to follow that will take you to a secure virtual meeting room. Once you have joined the online session, it will be locked to prevent anyone from joining.

How will information about me be used?
The data collected will be used to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The interview data will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about me?
Any personal information that has been collected about you during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. No hard copy data is expected to be produced as the consent forms and interview sessions will be online. All documents and responses from yourself will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371

(16/07/2020, V1.1)

Appendix 28 – Sixth form parent main study interview participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Parent Information sheet - Sixth Form Student Interview

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool in academic education. This study will involve the use of unique AR playing cards, developed by Keele University with help from your child, their teachers, and fellow students. The content of the cards include Biology and Chemistry topics that their older colleges and teachers have noted as being slightly more difficult to learn and understand. Your child has already been involved in earlier stages of this study and will be encouraged to participate in the final stage. Before your child decides whether or not they wish to take part, it is important for you both to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with your child if you wish. Ask us if there is anything that is unclear or if you would like more information.

Why have they been invited?

Your child has been invited to an interview as they have completed the majority of the previous step of my research project (pre and post questionnaires and quizzes) and also had hands on experience using the Pharma Compounds augmented reality App.

Do they have to take part?

You child is free to decide whether they wish to be interviewed. If they do decide to take part, they will be asked to confirm their consent through an online consent form that follows on from their information sheet.

What will happen if they take part?

If your child decides to take part, they will be asked to familiarise themselves with the AR learning tool before being invited to a short interview. They will be sent a weblink that will take them to a virtual interview room with the principal researcher. The interview should last no longer than 15 minutes.

Will they be recorded and how will the recorded media be used?

The interview audio will be recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without their written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?

Your child's' involvement will help shape the development of this app and similar augmented reality tools for use in their future studies.

What are the risks of taking part?
There are minimal risks to your child being involved with the interviews in this study. They will be sent a web link to follow that will take you to a secure virtual meeting room. Once they have joined the online session, it will be locked to prevent anyone else from joining.

How will information about your child be used?
The data collected will be used to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The interview data will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about your child?
Any personal information that has been collected about your child during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. No hard copy data is expected to be produced as the consent forms and interview sessions will be online. All documents and responses from your child will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from their responses may be used in future publications and reports however they will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you or your child have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you or your child remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

Research Integrity Team
Directorate of Research, Innovation and Engagement
IC2 Building
Keele University
Staffordshire
ST5 5NE
E-mail: research.governance@keele.ac.uk
Tel: 01782 733371

(21/07/2020, V1.0)

Appendix 29 – MPharm main study interview participant information sheet

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Undergraduate Stage 2 Pharmacy and Pharmaceutical Science Students

Participant Information

Why have I been invited?

You have been invited to an interview as you have completed the majority of the previous step of my research project (pre and post questionnaires and quizzes) and also had hands on experience using the Pharma Compounds augmented reality App.

Do I have to take part?

You are free to decide whether you wish to be interviewed. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here.

What will happen if I take part?

If you decide to take part, you will be asked to familiarise yourself with the AR learning tool before being invited to a short interview. You will be sent a weblink that will take you to a virtual interview room with the principal researcher. The interview should last no longer than 15 minutes.

Will I be recorded and how will the recorded media be used?

The interview audio will be recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?

Your involvement will help shape the development of this app and similar augmented reality tools for use in your future studies.

What are the risks of taking part?

There are minimal risks involved with the interviews in this study. You will be sent a web link to follow that will take you to a secure virtual meeting room. Once you have joined the online session, it will be locked to prevent anyone from joining.

How will information about me be used?

The data collected will be used to evaluate how effective an augmented reality learning tool/teaching aid can be in academic education. The interview data will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about me?
Any personal information that has been collected about you during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. No hard copy data is expected to be produced as the consent forms and interview sessions will be online. All documents and responses from yourself will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

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Tel: 01782 733371

(16/07/2020, V1.1)

Appendix 30 – Tutor main study interview participant information sheet

Evaluation of an Augmented Reality Learning Tool in Academic Education - Tutor Interview

Tutor interview Participant Information

My name is Deon Essel, I am a Pharmacist and PhD student at Keele University. I am conducting a research project that aims to evaluate the usefulness of an augmented reality (AR) learning tool (Pharma Compounds) in academic education. This study involves the use of unique AR playing cards, developed by Keele University with help from A-level and undergraduate students and tutors. The learning tool covers core principles of A-level Biology and Chemistry courses that applies to sections of the stage 2 MPharm and Pharmaceutical Science courses. Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and contact me if there is anything that is unclear or if you would like more information.

Why have I been invited?

You have been invited to participate in this study as a number of your students were given access to the AR learning tool during earlier stages of this research project.

Do I have to take part?

You are free to decide whether you wish to be interviewed. If you do decide to take part, you will be asked to confirm your consent through an online consent form that follows on from here.

What will happen if I take part?

If you decide to take part, you will be asked to familiarise yourself with the AR learning tool before being invited to a short interview. If you have not had the opportunity to encounter the AR learning tool, I will arrange for a set of the cards to be sent directly to you. The interview should last no longer than 20 minutes and will be conducted via telephone or video call depending on your convenience.

Will I be recorded and how will the recorded media be used?

The interview will be audio recorded, transcribed, and used for analysis. No other use will be made of the audio recordings without your written permission and no one outside of the project will have access to the original recordings.

What are the benefits of taking part?

Your participation will help shape the development of this app and similar augmented reality tools for educational use.

What are the risks of taking part?

There are minimal risks involved with the interviews in this study. If you chose a video call, you will be sent a web link to follow that will take you to a secure virtual meeting room. Once you have joined the online session, it will be locked to prevent anyone from joining. if you chose to have a telephone interview, a call will be made to a phone number you provide.

How will information about me be used?
The data collected will be used to evaluate how effective the AR learning tool/teaching aid can be in academic education. The interview data will be analysed and will not be passed on for use by third parties. The data collected may be published in reports and scientific literature, but all participant responses will be anonymised with personal details removed.

Who will have access to information about me?
Any personal information that will been collected about you during the course of the research will be kept strictly confidential and no one outside the project will be allowed to access it. Data collected will be stored on a password-protected and encrypted device that only my supervisory team and I have access to. No hard copy data is expected to be produced as the consent forms and interview recordings will be digital. All documents and responses from yourself will be electronic files or online documents. Should any hard copies of documents be generated at any stage of the study that contain participant responses, they will be secured in a locked cupboard that only my supervisory team and I have access to. At the end of the study all data and documents gathered will be destroyed. Quotes taken from your responses may be used in future publications and reports however you will not be identifiable as all identifiable data or remarks will be anonymised.

Who is funding and organising the research?
The School of Pharmacy at Keele University has provided funding for this study.

What if there is a problem?
If you have a concern about any aspect of this study, you can contact

Deon Essel, principal researcher, PhD student, d.essel@keele.ac.uk

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study, please write to the Research Integrity Team at the address below:-

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E-mail: research.governance@keele.ac.uk
Tel: 01782 733371

(16/07/2020, V1.1)

Appendix 31 – Sixth form main study consent form

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Consent Form

1. I confirm that I have read and understood the information sheet (dated 20/11/2018 v1.2) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am able to withdraw from the study up until 7 days after submitting the consent form in the event of withdrawal, and where it is possible, relevant data will also be withdrawn.

3. I understand that the data collected will be anonymised before it is used in any reports or publications

4. I agree for my response to be anonymised and used as quotes in any reports or publications

I agree to join the study

☐ Agree

Please provide your full name (First, Surname)

(20/11/2018 v1.2)

Appendix 32 – MPharm main study consent form

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Undergraduate Stage 2 Pharmacy and Pharmaceutical Science Students

Consent form

1. I confirm that I have read and understood the information sheet (dated 20/11/2018 v1.2) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am able to withdraw from the study up until 7 days after submitting the consent form in the event of withdrawal, and where it is possible, relevant data will also be withdrawn.

3. I understand that the data collected will be anonymised before it is used in any reports or publications

4. I agree for my response to be anonymised and used as quotes in any reports or publications

I agree to join the study

☐ Agree

Please provide your full name (First, Surname)

(20/11/2018 v1.2)

Appendix 33 – Sixth form main study interview consent form

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Year 12 Sixth Form/College Students

Consent From

Name and contact details of Principal Investigator: Deon Essel, d.essel@keele.ac.uk

Please check the box if you agree with the statement

☐ I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
☐ I understand that my participation is voluntary.
☐ I agree to take part in this study.
☐ I understand that data collected about me during this study will be anonymised before it is submitted for publication.
☐ I agree to the interview being recorded

CONSENT FOR USE OF QUOTES

Please check the box if you agree with the statement
☐ I agree for any quotes to be used
☐ I do not agree for any quotes to be used

Full name of participant (First name and last name)

Please provide the same email address that you used throughout the course of the study

(12/06/2020, V1.0)

Appendix 34 – MPharm main study interview consent form

An Evaluation of An Augmented Reality Learning Tool in Academic Education - Undergraduate Stage 2 Pharmacy Students

Consent From

Name and contact details of Principal Investigator: Deon Essel, d.essel@keele.ac.uk

Please check the box if you agree with the statement

☐ I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
☐ I understand that my participation is voluntary.
☐ I agree to take part in this study.
☐ I understand that data collected about me during this study will be anonymised before it is submitted for publication.
☐ I agree to the interview being recorded

CONSENT FOR USE OF QUOTES

Please check the box if you agree with the statement
☐ I agree for any quotes to be used
☐ I do not agree for any quotes to be used

Full name of participant (First name and last name)

Please provide the same email address that you used throughout the course of the study

(12/06/2020, V1.1)

Appendix 35 – Tutor main study interview consent form

Evaluation of an Augmented Reality Learning Tool in Academic Education - Tutor Interview

Consent From

Name and contact details of Principal Investigator: Deon Essel, d.essel@keele.ac.uk

Please check the box if you agree with the statement

☐ I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
☐ I understand that my participation is voluntary.
☐ I agree to take part in this study.
☐ I understand that data collected about me during this study will be anonymised before it is submitted for publication.
☐ I agree to the interview being recorded

CONSENT FOR USE OF QUOTES

Please check the box if you agree with the statement
☐ I agree for any quotes to be used
☐ I do not agree for any quotes to be used

Full name of participant (First name and last name)

Please provide an email address

(12/06/2020, V1.0)

Appendix 36 – Sixth form main study pre-questionnaire

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide an email address that will be used throughout the course of the study

Pre-questionnaire

What gender do you mostly identify with?
☐ Male
☐ Female
☐ Prefer not to say
☐ Other

What age group do you belong to?
☐ 16 - 17 years
☐ 18 - 19 years
☐ 19+ years

In what country do you study?
☐ United Kingdom
☐ Hong Kong
☐ Kenya

What type of 6th form/college do you attend?
☐ Independent/Private
☐ State

What course are you currently enrolled on?
☐ Biology
☐ Chemistry
☐ Biology and Chemistry

Have you ever been involved in a research project before?
☐ Yes
☐ No

From what you know, what do research projects involve?

Can you define "Augmented Reality" in one sentence?

Have you ever used an augmented reality device and if so, can you name what device it was?

Do you agree with the use of mobile devices (tablets, smartphones etc.) in teaching sessions?

Strongly disagree				Strongly agree
1	2	3	4	5

Which of the following methods of teaching have you experienced?

- ☐ Computer-generated simulations
- ☐ Demonstrations
- ☐ Laboratory sessions
- ☐ Lectures
- ☐ Workshops

How would you rate your motivation towards learning while using computer-generated simulations?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in demonstration?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in laboratory sessions?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in lectures?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in workshops?

Very demotivated				Very motivated
1	2	3	4	5

What about the current methods of teaching that you have experienced motivates you the most to learn?

What different methods do you use when revising material you have already covered in class?

How would you rate your motivation towards learning when revising using your current methods?

Very demotivated				Very motivated
1	2	3	4	5

Self-reported Motivation

For each of the following, please indicate how true the statement is for you

I enjoy my current learning/revision methods very much

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

While I learn/revise using my current methods, I think about how much I enjoyed it

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think using my current learning/revision methods could help me to improve my academic performance

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would describe my current learning/revision methods as very interesting

Not true at all			Somewhat true			Very true

1 2 3 4 5 6 7

I believe my current learning/revision methods are of some value to me

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

My current learning/revision methods do not hold my attention at all (R)

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

My current learning/revision methods are fun to use

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I think my current learning/revision methods are boring (R)

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I think that it is important to use my current learning/revision methods because it can develop visualisation skills

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I think my current learning/revision methods are quite enjoyable

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

Appendix 37 – Sixth form main study post-questionnaire

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide the same email address you used in the previous stages of the study

Post-questionnaire

How would you define augmented reality in one sentence?

How difficult/easy did you find the PharmaCompounds learning tool to use?

Very difficult				Very easy
1	2	3	4	5

On average, how many times a week did you use the PharmaCompounds learning tool?

☐ Less than twice week
☐ 2 - 4 times a week
☐ 5 - 7 times a week
☐ More than 7 times a week

How did using the PharmaCompounds learning tool effect your personal revision sessions?

How did using the PharmaCompounds learning tool effect group learning sessions?

What do you think are the main advantages of the AR PharmaCompounds learning tool?

What do you think are the main disadvantages of the AR PharmaCompounds learning tool?

In what way has the PharmaCompounds learning tool effected your learning process?

How would you rate your ability to visualise similar learning material after using the AR PharmaCompounds learning tool?

Very difficult				Very easy
1	2	3	4	5

In what way do you think your motivation towards learning change as a result of using the PharmaCompounds learning tool?

How would you like the AR PharmaCompounds learning tool to be used in your future teaching sessions?

How would you improve the AR PharmaCompounds learning tool?

Self-reported Motivation

For each of the following, please indicate how true the statement is for you

I enjoyed using the PharmaCompounds learning tool very much

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

While using the PharmaCompounds learning tool, I was thinking about how much I enjoyed it

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think using the PharmaCompounds learning tool could help me to improve my academic performance

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would describe the PharmaCompounds learning tool learning tool as very interesting

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I believe the PharmaCompounds learning tool learning tool could be of some value to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

The PharmaCompounds learning tool did not hold my attention at all (R)

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

The PharmaCompounds learning tool was fun to use

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would be willing to use the PharmaCompounds learning tool again because it has some value to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think the PharmaCompounds learning tool is useful for visualising difficult material

Not true at all	Somewhat true	Very true

1	2	3	4	5	6	7

I think the PharmaCompounds learning tool is an important revision/learning tool

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I thought the PharmaCompounds learning tool was boring. (R)

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think that it is important to use the PharmaCompounds learning tool because it can develop my visualisation skills

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I thought the PharmaCompounds learning tool was quite enjoyable

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I believe using the PharmaCompounds learning tool could be beneficial to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

Appendix 38 – MPharm main study pre-questionnaire

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide an email address that will be used throughout the course of the study

Pre-questionnaire

What gender do you mostly identify with?
☐ Male
☐ Female
☐ Prefer not to say
☐ Other

What age group do you belong to?
☐ 18 - 21 years
☐ 22 - 25 years
☐ 25+ years

Are you enrolled as an international or domestic student?
☐ International student
☐ Domestic student

Have you ever been involved in a research project before?
☐ Yes
☐ No

From what you know, what do research projects involve?

Can you define "Augmented Reality" in one sentence?

Have you ever used an augmented reality device and if so, can you name what device it was?

Do you agree with the use of mobile devices (tablets, smartphones etc.) in teaching sessions?

Strongly disagree				Strongly agree
1	2	3	4	5

Which of the following methods of teaching have you experienced?

☐ Computer-generated simulations
☐ Demonstrations
☐ Laboratory sessions
☐ Lectures
☐ Workshops

How would you rate your motivation towards learning while using computer-generated simulations?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in demonstration?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in laboratory sessions?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in lectures?

Very demotivated				Very motivated
1	2	3	4	5

How would you rate your motivation towards learning while in workshops?

Very demotivated				Very motivated
1	2	3	4	5

What about the current methods of teaching that you have experienced motivates you the most to learn?

What different methods do you use when revising material you have already covered in class?

How would you rate your motivation towards learning when revising using your current methods?

Very demotivated				Very motivated
1	2	3	4	5

Self-reported Motivation

For each of the following, please indicate how true the statement is for you

I enjoy my current learning/revision methods very much

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

While I learn/revise using my current methods, I think about how much I enjoyed it

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think using my current learning/revision methods could help me to improve my academic performance

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would describe my current learning/revision methods as very interesting

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I believe my current learning/revision methods are of some value to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

My current learning/revision methods do not hold my attention at all (R)

Not true at all	Somewhat true	Very true

1	2	3	4	5	6	7

My current learning/revision methods are fun to use

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think my current learning/revision methods are boring (R)

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think that it is important to use my current learning/revision methods because it can develop visualisation skills

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think my current learning/revision methods are quite enjoyable

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

Appendix 39 – MPharm main study post-questionnaire

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide an email address that will be used throughout the course of the study

Post-questionnaire

How would you define augmented reality in one sentence?

How difficult/easy did you find the PharmaCompounds learning tool to use?

Very difficult				Very easy
1	2	3	4	5

On average, how many times a week did you use the PharmaCompounds learning tool?

☐ Less than twice week
☐ 2 - 4 times a week
☐ 5 - 7 times a week
☐ More than 7 times a week

How did using the PharmaCompounds learning tool effect your personal revision sessions?

How did using the PharmaCompounds learning tool effect group learning sessions?

What do you think are the main advantages of the AR PharmaCompounds learning tool?

What do you think are the main disadvantages of the AR PharmaCompounds learning tool?

In what way has the PharmaCompounds learning tool effected your learning process?

How would you rate your ability to visualise similar learning material after using the AR PharmaCompounds learning tool?

Very difficult				Very easy
1	2	3	4	5

In what way do you think your motivation towards learning change as a result of using the PharmaCompounds learning tool?

How would you like the AR PharmaCompounds learning tool to be used in your future teaching sessions?

How would you improve the AR PharmaCompounds learning tool?

Self-reported Motivation

For each of the following, please indicate how true the statement is for you

I enjoyed using the PharmaCompounds learning tool very much

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

While using the PharmaCompounds learning tool, I was thinking about how much I enjoyed it

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think using the PharmaCompounds learning tool could help me to improve my academic performance

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would describe the PharmaCompounds learning tool learning tool as very interesting

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I believe the PharmaCompounds learning tool learning tool could be of some value to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

The PharmaCompounds learning tool did not hold my attention at all (R)

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

The PharmaCompounds learning tool was fun to use

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I would be willing to use the PharmaCompounds learning tool again because it has some value to me

Not true at all			Somewhat true			Very true
1	2	3	4	5	6	7

I think the PharmaCompounds learning tool is useful for visualising difficult material

Not true at all	Somewhat true	Very true

1 2 3 4 5 6 7

I think the PharmaCompounds learning tool is an important revision/learning tool

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I thought the PharmaCompounds learning tool was boring. (R)

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I think that it is important to use the PharmaCompounds learning tool because it can develop my visualisation skills

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I thought the PharmaCompounds learning tool was quite enjoyable

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

I believe using the PharmaCompounds learning tool could be beneficial to me

Not true at all Somewhat true Very true

1 2 3 4 5 6 7

Appendix 40 – Sixth form main study pre-quiz

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide the same email address you used in the previous stages of the study

Pre-Quiz

What subject(s) do you study?

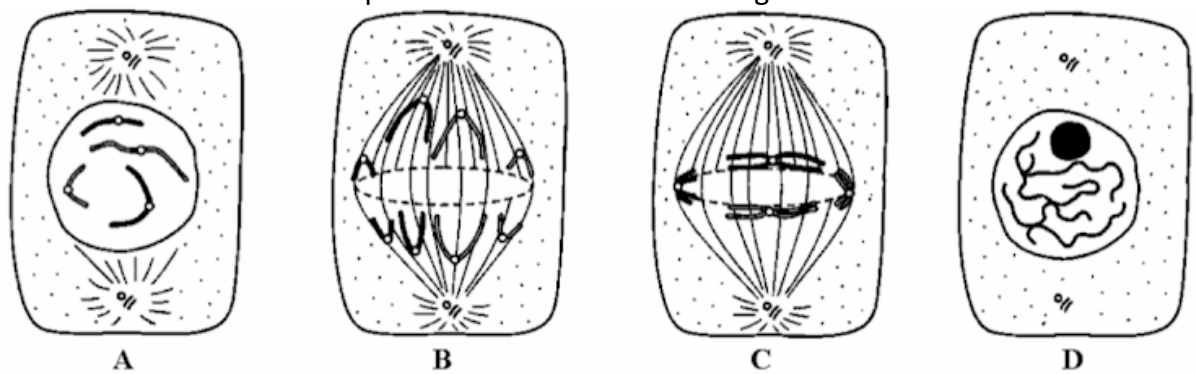
☐ Biology
☐ Chemistry
☐ Biology and Chemistry

Biology Pre-Quiz

Sucrose is formed from the reaction between glucose and fructose. Both have the chemical formula $C_6H_{12}O_6$. What is the chemical formula of sucrose?

☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{22}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{11}$

The diagram below shows a cell at four different stages in mitosis. Which of the options below shows the correct sequence in which these four stages occur?



☐ D, A, C, B
☐ A, D, C, B
☐ D, A, B, C
☐ A, B, C, D

Glycogen is a complex carbohydrate found in the liver of mammals. Which of the following statements is/are true?

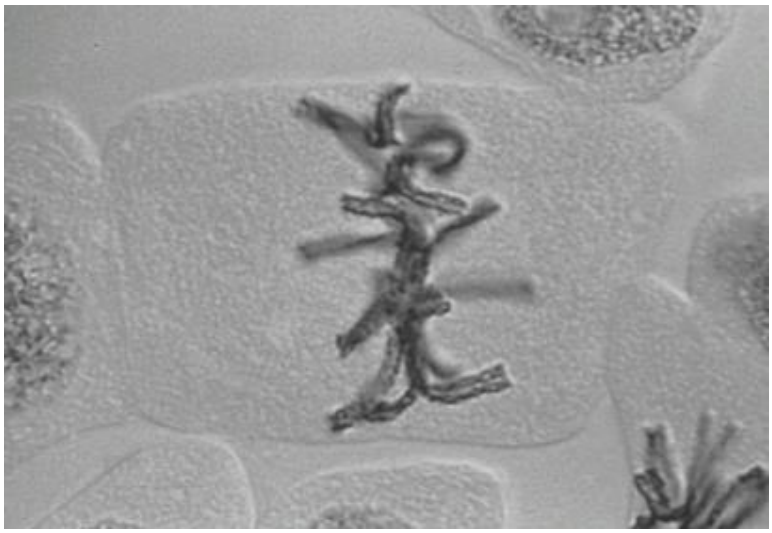
Statement 1: Glycogen contains 1, 4 glycosidic bonds between alpha glucose molecules

Statement 2: Glycogen contains 1, 6-glycosidic bonds between alpha glucose molecules

Statement 3: Branches occur within the glycogen molecule by the formation of 1-6 glycosidic bonds

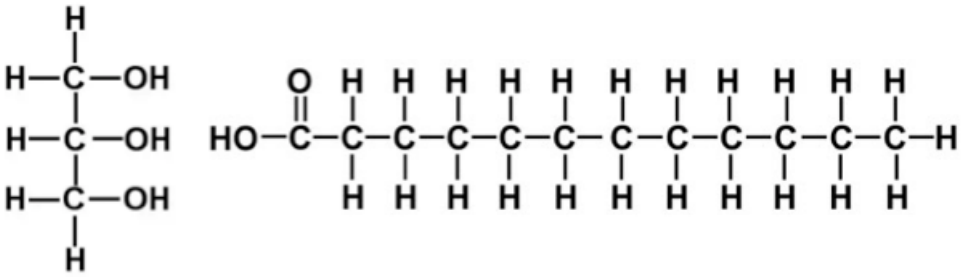
☐ Statement 1
☐ Statements 1 and 2
☐ Statements 2 and 3
☐ Statements 1, 2 and 3

The image below shows a stage in mitosis. Which of the following options is the stage of mitosis shown?



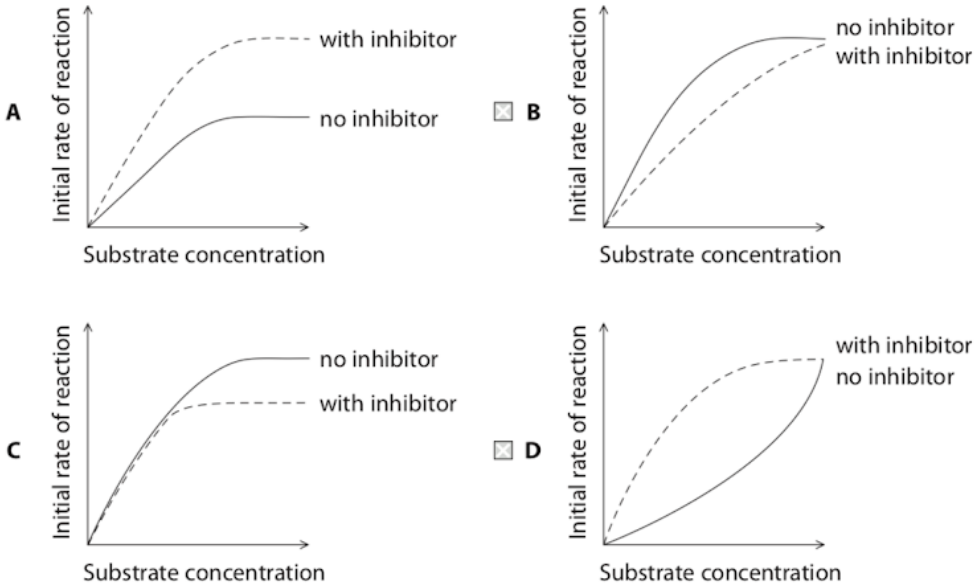
☐ Anaphase
☐ Metaphase
☐ Prophase
☐ Telophase

Glycerol and fatty acid molecules are used in the synthesis of cell membranes. which of the statements below describes the reaction when these two molecules join together?



☐ A condensation reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond
☐ A hydrolysis reaction forming an ester bond
☐ A hydrolysis reaction forming a glycosidic bond

Succinate dehydrogenase is an enzyme found in mitochondria. Succinate dehydrogenase converts succinate to fumarate. The enzyme's activity is competitively inhibited by malonate. Which of the graphs represents the effect of this type of inhibitor?



☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

Students made a squash preparation of a root tip to observe the stages of mitosis. The students uses the following statements to identify cells in metaphase. Which statement is correct?

Statement 1: Pairs of homologous chromosomes lined up along the equator of each cell
Statement 2: Crossing over taking place
Statement 3: Chromatids visible

☐ Statement 1
☐ Statement 2
☐ Statement 3

Carbohydrates, such as starch are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of starch together?

☐ Phosphodiester
☐ Ester
☐ Glycosidic
☐ Peptide

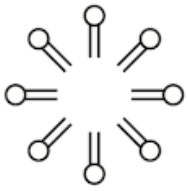
A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence

	Complementary DNA sequence	mRNA sequence
A	AATCGCGGTCGCTCA	UUAGCGCCAGCGAGU
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

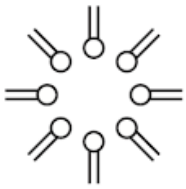
☐ Row A
☐ Row B
☐ Row C
☐ Row D

When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution

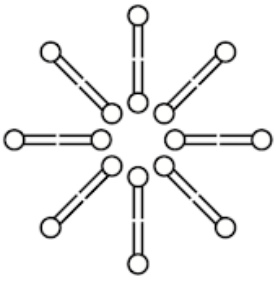
A



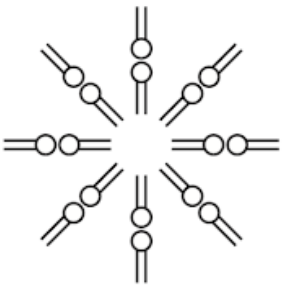
B



C

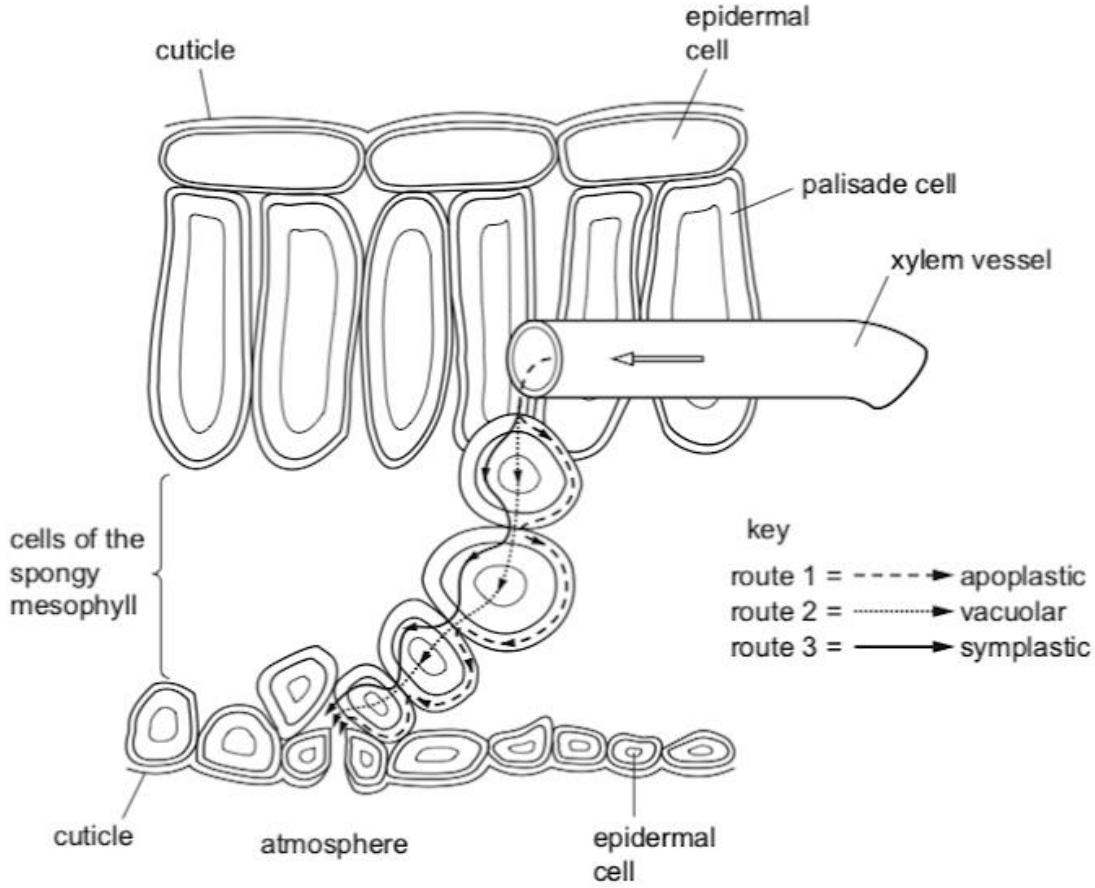


D



☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Water passes across leaf tissues by different routes as a result of differences in water potential or the pull transmitted by cohesive forces between water molecules



Which row correctly identifies why water passes across leaf tissues by the different routes?

	differences in water potential	pull transmitted by cohesive forces
A	route 1	routes 2 and 3
B	routes 1 and 3	route 2
C	route 2	routes 1 and 3
D	routes 2 and 3	route 1

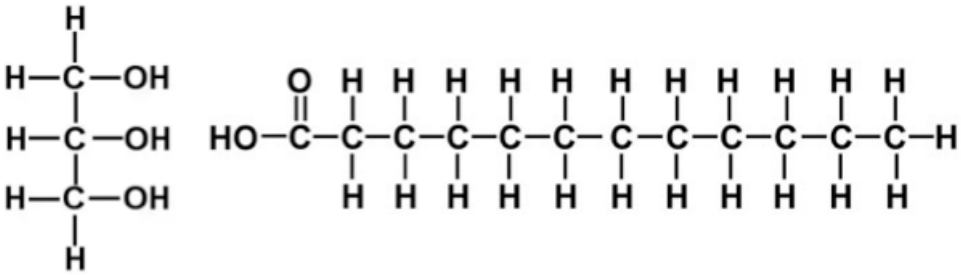
☐ Row A
☐ Row B
☐ Row C
☐ Row D

Chemistry Pre-Quiz

Sucrose is formed from the reaction between glucose and fructose. Both have the chemical formula $C_6H_{12}O_6$. What is the chemical formula of sucrose?

☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{22}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{11}$

Glycerol and fatty acid molecules are used in the synthesis of cell membranes. which of the statements below describes the reaction when these two molecules join together?



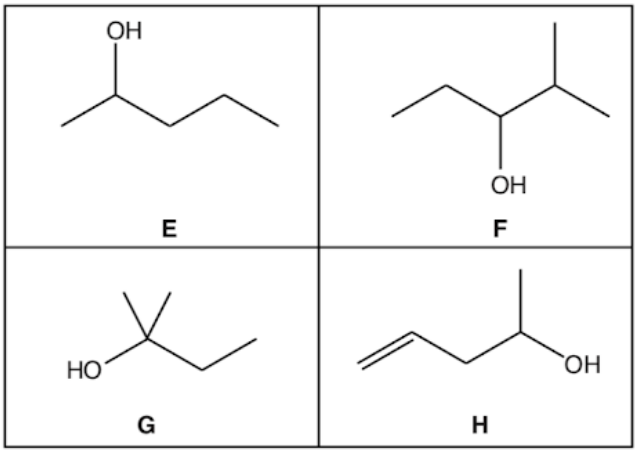
☐ A condensation reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond
☐ A hydrolysis reaction forming an ester bond
☐ A hydrolysis reaction forming a glycosidic bond

Which of the following formulae represents a saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

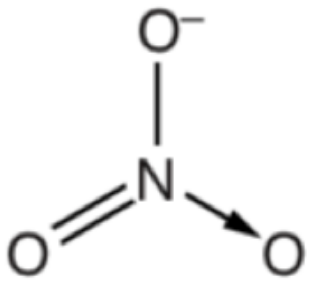
☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

The skeletal formulae of four alcohols are shown below. Which pair are structural isomers of one another?

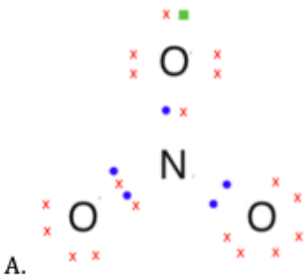


- ☐ E and F
- ☐ E and G
- ☐ E and H
- ☐ F and G

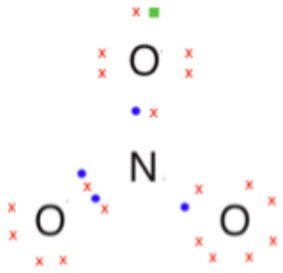
$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.



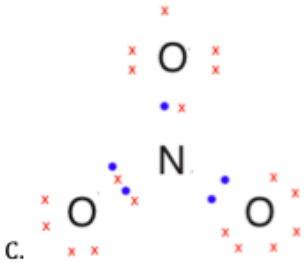
Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.



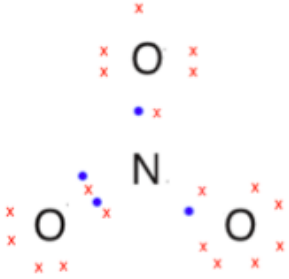
A.



B.



C.



D.

- ☐ Diagram A
- ☐ Diagram B
- ☐ Diagram C

☐ Diagram D

Which of these molecules has a tetrahedral shape?

☐ H_20

☐ NH_4^+

□ BF_3

☐ NH^3

The properties of elements and their compounds are determined by their structure and bonding. Diamond is very hard and strong with a high melting point. which of the following is the best description of its structure and bonding?

☐ Giant ionic

☐ Giant metallic

☐ Giant covalent

☐ Simple covalent

What type of compound is ethyl ethanoate?

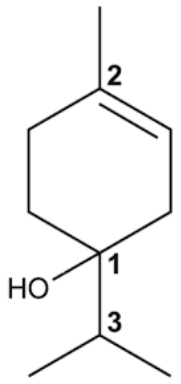
☐ Aldehyde

☐ Ester

☐ Alcohol

☐ Ketone

One of the active ingredients in tea area oil is terpinen-4-ol. In the diagram of skeletal formula of terpinen-4-ol, three of the carbon atoms are labelled 1, 2 and 3. Which of the labelled carbon atoms are chiral?



terpinen-4-ol

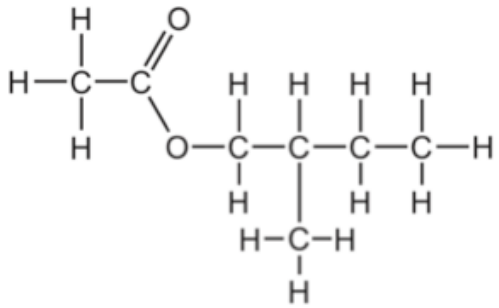
☐ Atom 1

☐ Atom 2

☐ Atom 3

☐ Atoms 1, 2 and 3

Bees use 2-methylbutyl ethanoate as an 'alarm' pheromone to alert other bees



2-methylbutyl ethanoate

Which starting material would be required to synthesis 2-methylbutyl ethanoate?

A. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CO_2H$
B. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2OH$
C. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CH_2CO_2H$
D. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2CO_2H$

☐ Molecules A
☐ Molecules B
☐ Molecules C
☐ Molecules D

Biology and Chemistry Pre-Quiz

Sucrose is formed from the reaction between glucose and fructose. Both have the chemical formula $C_6H_{12}O_6$. What is the chemical formula of sucrose?

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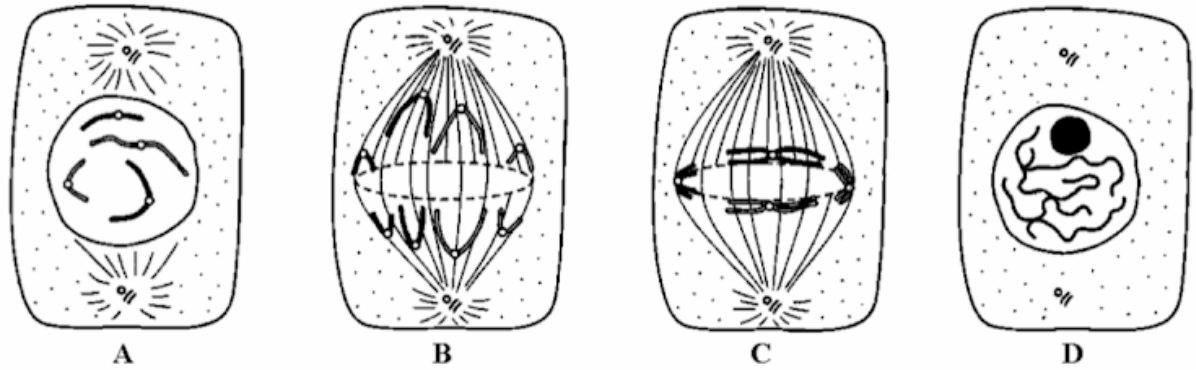
The diagram below shows a cell at four different stages in mitosis. Which of the options below shows the correct sequence in which these four stages occur?



☐ D, A, C, B
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Glycogen is a complex carbohydrate found in the liver of mammals. Which of the following statements is/are true?

Statement 1: Glycogen contains 1, 4 glycosidic bonds between alpha glucose molecules

Statement 2: Glycogen contains 1, 6-glycosidic bonds between alpha glucose molecules

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☐ Statement 1
☐ Statements 1 and 2
☐ Statements 2 and 3
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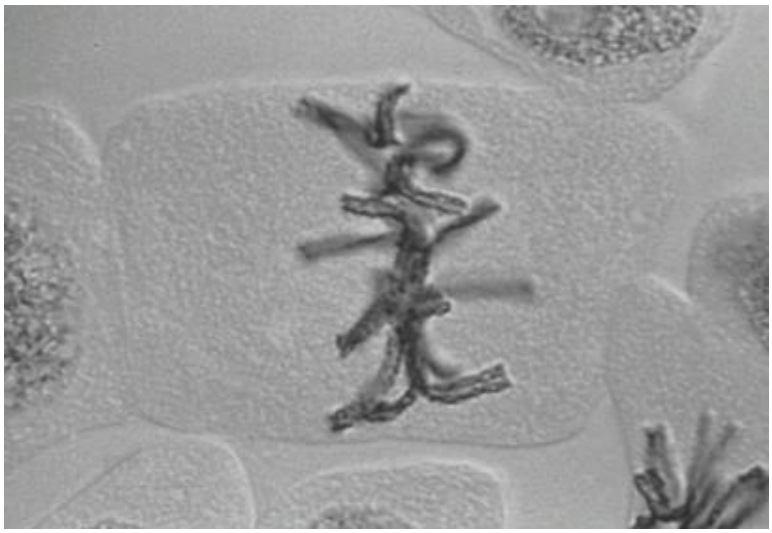
The image below shows a stage in mitosis. Which of the following options is the stage of mitosis shown?



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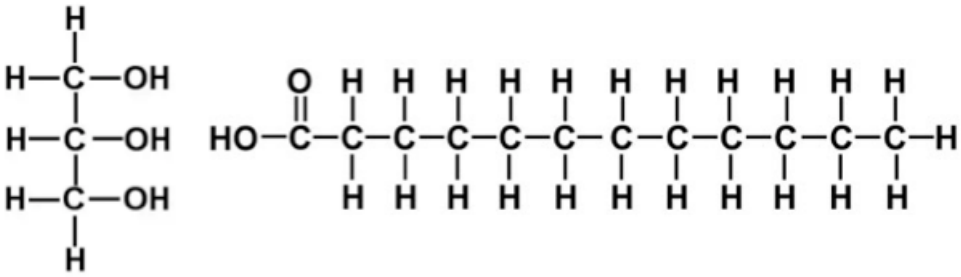
Glycerol and fatty acid molecules are used in the synthesis of cell membranes. which of the statements below describes the reaction when these two molecules join together?



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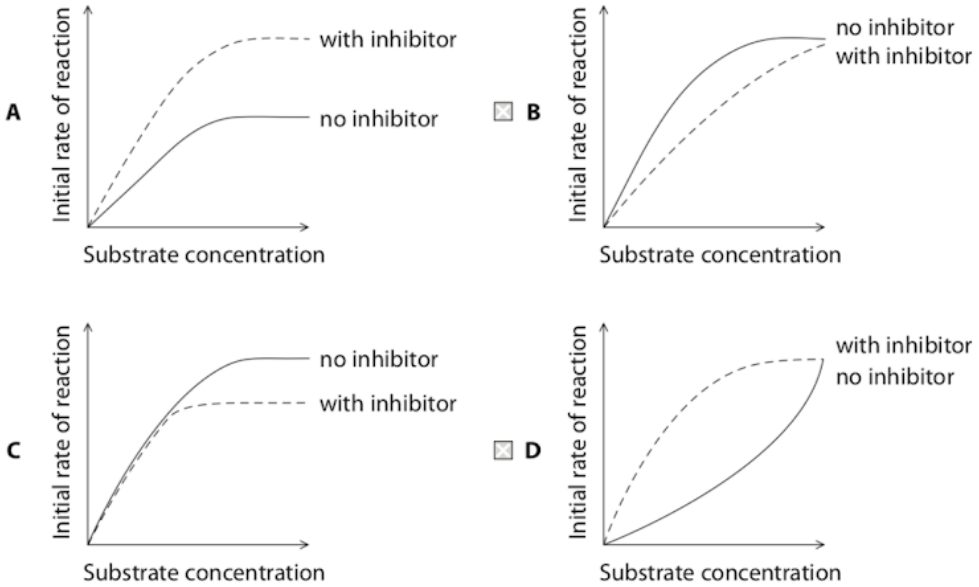
Succinate dehydrogenase is an enzyme found in mitochondria. Succinate dehydrogenase converts succinate to fumarate. The enzyme's activity is competitively inhibited by malonate. Which of the graphs represents the effect of this type of inhibitor?



☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

Students made a squash preparation of a root tip to observe the stages of mitosis. The students uses the following statements to identify cells in metaphase. Which statement is correct?

Statement 1: Pairs of homologous chromosomes lined up along the equator of each cell
Statement 2: Crossing over taking place
Statement 3: Chromatids visible

☐ Statement 1
☐ Statement 2
☐ Statement 3

Carbohydrates, such as starch are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of starch together?

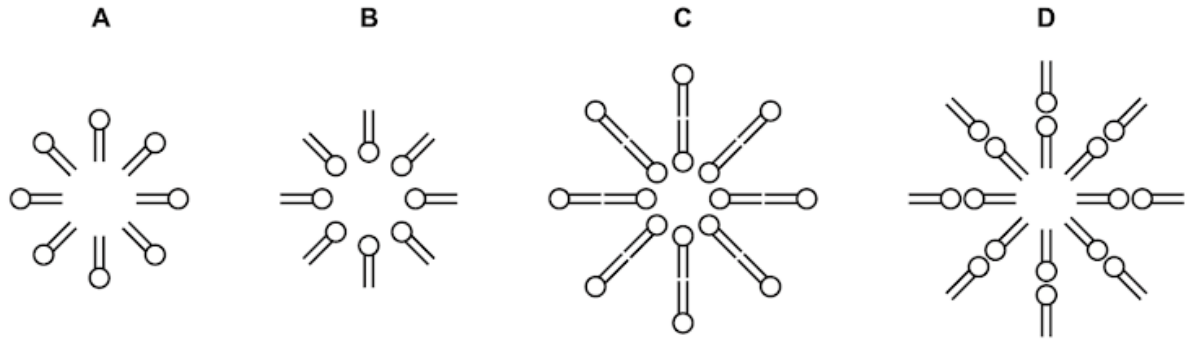
☐ Phosphodiester
☐ Ester
☐ Glycosidic
☐ Peptide

A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence above

	Complementary DNA sequence	mRNA sequence
A	AATCGCGGTCGCTCA	UUAGCGCCAGCGAGU
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

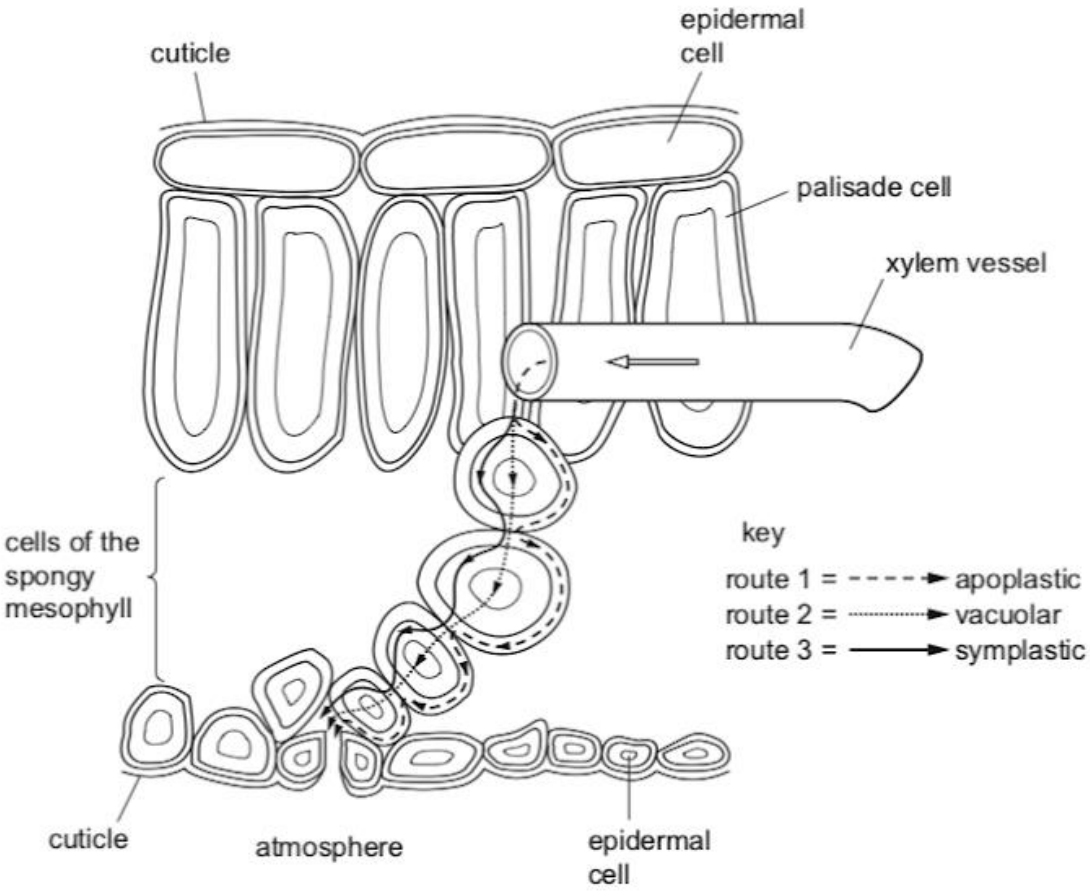
☐ Row A
☐ Row B
☐ Row C
☐ Row D

When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution



☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Water passes across leaf tissues by different routes as a result of differences in water potential or the pull transmitted by cohesive forces between water molecules



Which row correctly identifies why water passes across leaf tissues by the different routes?

	differences in water potential	pull transmitted by cohesive forces
A	route 1	routes 2 and 3
B	routes 1 and 3	route 2
C	route 2	routes 1 and 3
D	routes 2 and 3	route 1

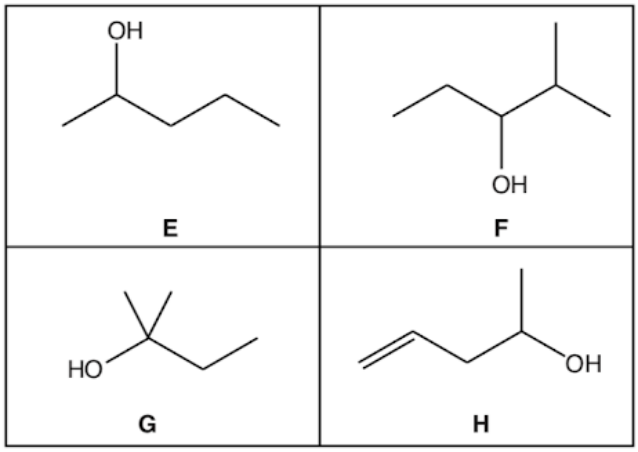
☐ Row A
☐ Row B
☐ Row C
☐ Row D

Which of the following formulae represents a saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

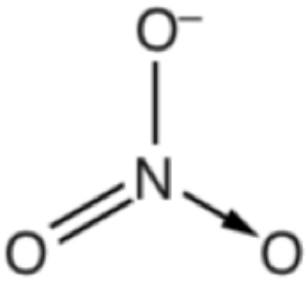
☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

The skeletal formulae of four alcohols are shown below. Which pair are structural isomers of one another?

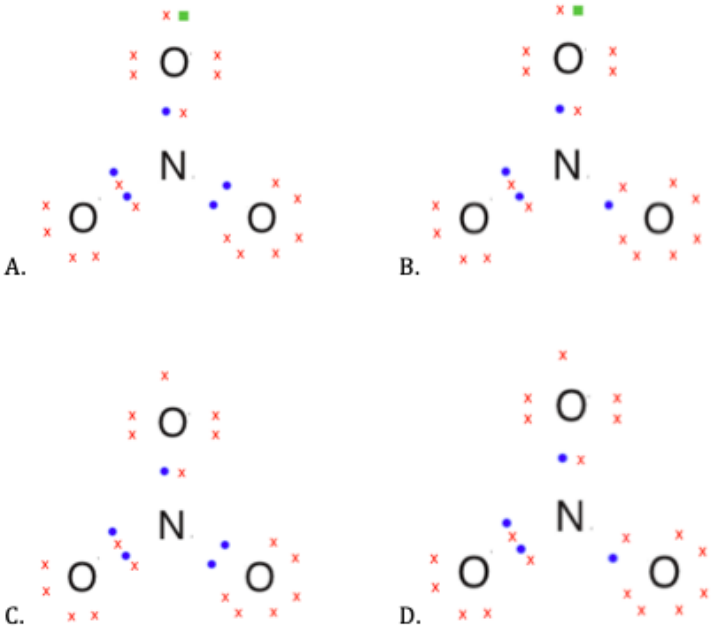


☐ E and F
☐ E and G
☐ E and H
☐ F and G

$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.



Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.



☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of these molecules has a tetrahedral shape?

☐ H_2O
☐ NH_4^+
□ BF_3
☐ NH^3

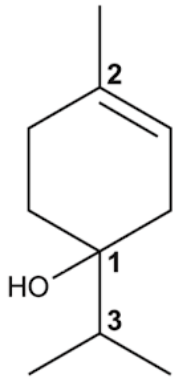
The properties of elements and their compounds are determined by their structure and bonding. Diamond is very hard and strong with a high melting point. which of the following is the best description of its structure and bonding?

☐ Giant ionic
☐ Giant metallic
☐ Giant covalent

☐ Simple covalent

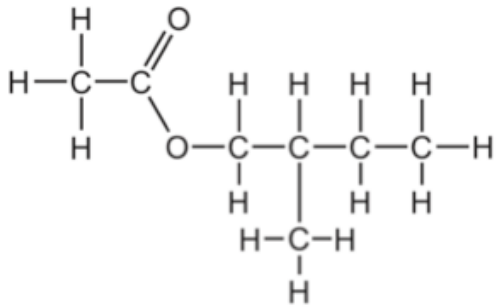
What type of compound is ethyl ethanoate?
☐ Aldehyde
☐ Ester
☐ Alcohol
☐ Ketone

One of the active ingredients in tea area oil is terpinen-4-ol. In the diagram of skeletal formula of terpinen-4-ol, three of the carbon atoms are labelled 1, 2 and 3. Which of the labelled carbon atoms are chiral?
☐ Atom 1
☐ Atom 2
☐ Atom 3
☐ Atoms 1, 2 and 3



terpinen-4-ol

Bees use 2-methylbutyl ethanoate as an 'alarm' pheromone to alert other bees



2-methylbutyl ethanoate

Which starting material would be required to synthesis 2-methylbutyl ethanoate?

A. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CO_2H$
B. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2OH$
C. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CH_2CO_2H$
D. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2CO_2H$

☐ Molecules A
☐ Molecules B
☐ Molecules C
☐ Molecules D

Appendix 41 – Sixth form main study post-quiz

An Evaluation of An Augmented Reality learning tool in Academic Education

Please provide the same email address you used in the previous stages of the study

Post-quiz

What subject(s) do you study?

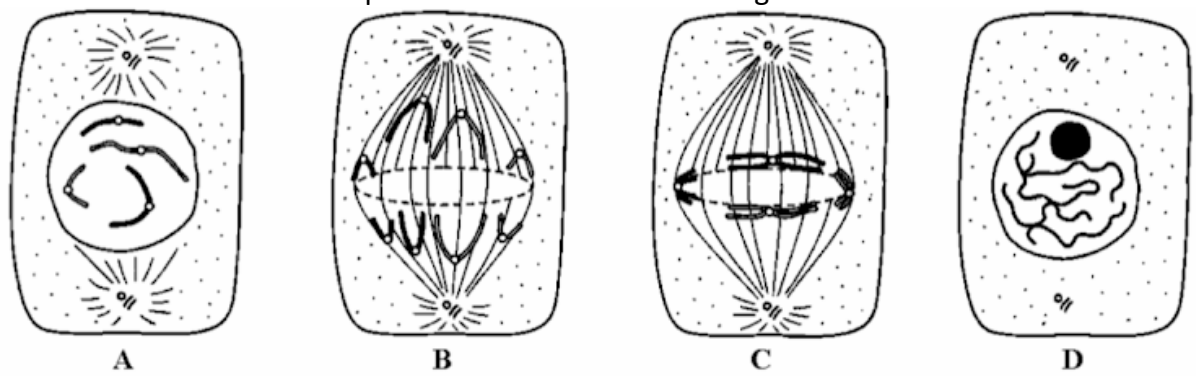
☐ Biology
☐ Chemistry
☐ Biology and Chemistry

Biology Pre-Quiz

Maltose is formed from the reaction between two glucose molecules. Glucose has the chemical formula C6H12O6. What is the chemical formula of maltose?

☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{11}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{22}$

The diagram below shows a cell at four different stages in mitosis. Which of the options below shows the correct sequence in which these four stages occur?



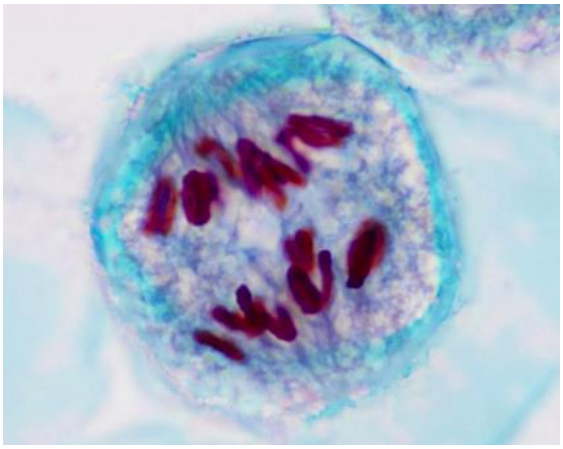
☐ D, A, C, B
☐ A, D, C, B
☐ D, A, B, C
☐ A, B, C, D

Amylopectin is a complex carbohydrate found in the plants. It is similar to glycogen in that it is made up of glucose monomers with the same chain bonding. Which of the following statements is/are true?

Statement 1: **A**mylopectin contains 1, 4 glycosidic bonds between glucose molecules
Statement 2: Amylopectin contains 1, 6 glycosidic bonds between glucose molecules
Statement 3: Branches occur within the amylopectin molecule by the formation of 1-6 glycosidic bonds

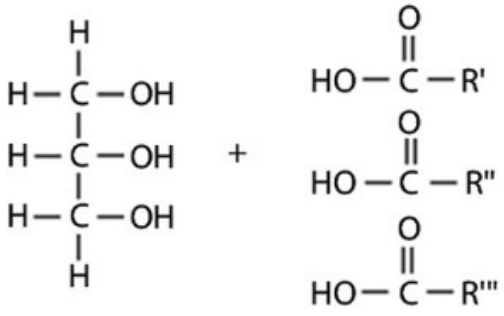
☐ Statement 1
☐ Statements 1 and 2
☐ Statements 2 and 3
☐ Statements 1, 2 and 3

The image below shows an animal cell undergoing mitosis. Which stage of mitosis is shown in the image below?



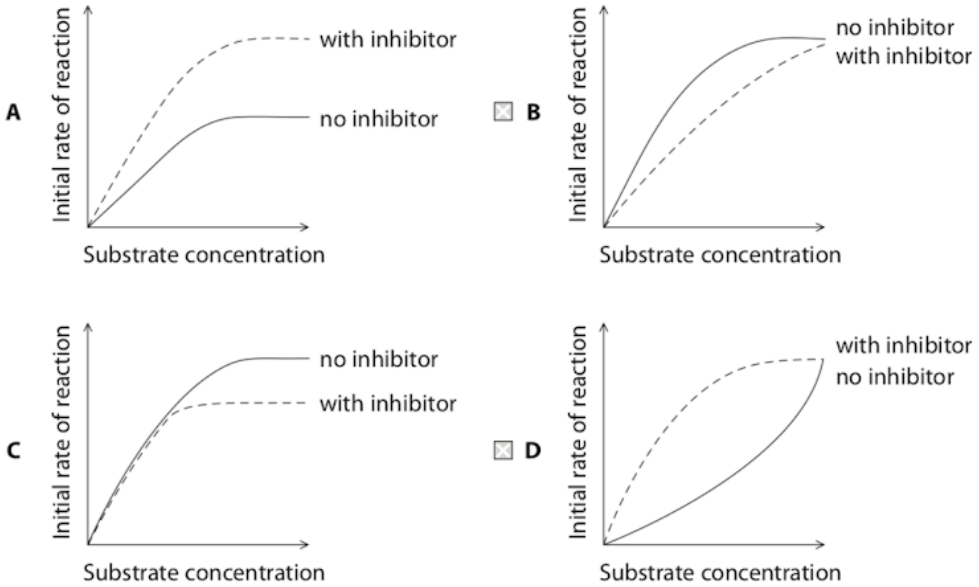
☐ Anaphase
☐ Metaphase
☐ Prophase
☐ Telophase

Glycerol and fatty acid molecules are used in the synthesis of triglycerides. which of the statements below describes the reaction when these two molecules join together?



☐ A hydrolysis reaction forming a glycosidic bond
☐ A condensation reaction forming an ester bond
☐ A hydrolysis reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond

Dihydropteroate synthase is an enzyme found in humans that contributes to the production of folic acid. The enzyme's activity is competitively inhibited by a drug called Sufanilamide. Which of the graphs represents the effect if this type of inhibitor?



☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

A students made a squash preparation of a root tip to observe the stages of mitosis. The students uses the following statements to identify cells in metaphase. Which statements are NOT correct?

Statement 1: Pairs of homologous chromosomes lined up along the equator of each cell
Statement 2: Crossing over taking place
Statement 3: Chromatids visible

☐ Statement 1, 2 and 3
☐ Statement 2 and 3
☐ Statement 1 and 3

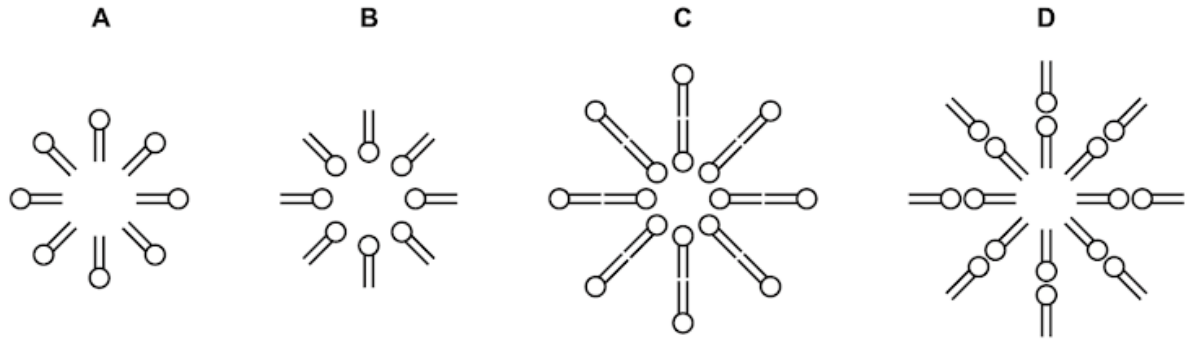
Carbohydrates, such as glycogen are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of glycogen together?
☐ Phosphodiester
☐ Ester
☐ Glycosidic
☐ Peptide

A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence

	Complementary DNA sequence	mRNA sequence
A	AATCGCGGTCGCTCA	UUAGCGCCAGCGAGU
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

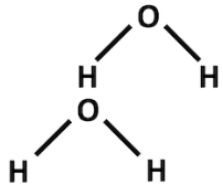
☐ Row A
☐ Row B
☐ Row C
☐ Row D

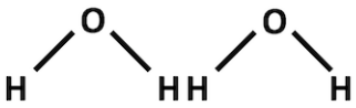
When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution

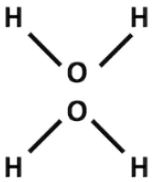


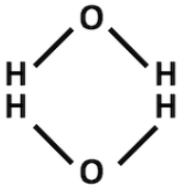
☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following is the most likely way that two water molecules will interact?

Ⓐ 

Ⓑ 

Ⓒ 

Ⓓ 

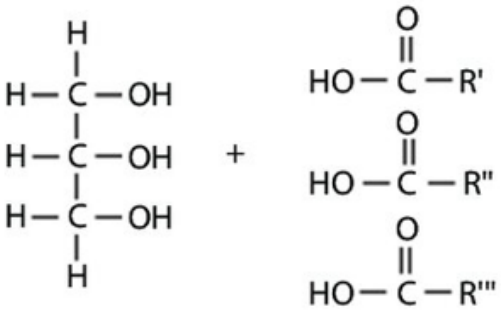
☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Chemistry Post-Quiz

Maltose is formed from the reaction between two glucose molecules. Glucose has the chemical formula C6H12O6. What is the chemical formula of maltose?

☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{11}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{22}$

Glycerol and fatty acid molecules are used in the synthesis of triglycerides. which of the statements below describes the reaction when these two molecules join together?



☐ A hydrolysis reaction forming a glycosidic bond
☐ A condensation reaction forming an ester bond
☐ A hydrolysis reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond

Which of the following formulae are NOT representations of saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

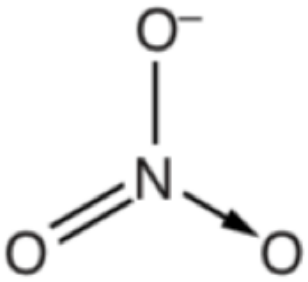
☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

For which of the compounds below are cis-trans isomers possible?

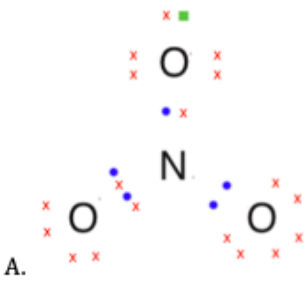
1) $CH_3CH=CH_2$ 2) $CH_3CH=CHCH_2CH_3$ 3) $CH_3CH=CHCH_3$

☐ Only 2
☐ Both 1 and 2
☐ Both 2 and 3
☐ 1, 2 and 3

$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.

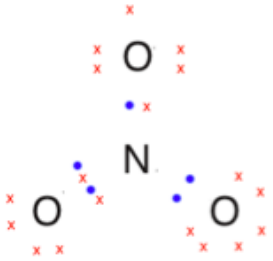


Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.

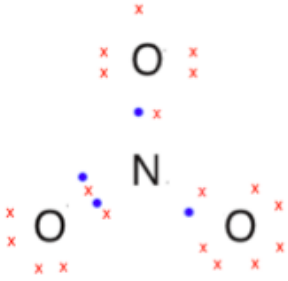


A.

B.



C.



D.

☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of these molecules has a trigonal planar shape?

☐ NH_3
☐ BF3
☐ BeH_2
☐ H_2O

The Properties of elements and their compounds are determined by their structure and bonding. Silicon Dioxide (silica) is very hard and strong with a high melting point. which of the following is the best description of its structure and bonding?

☐ Giant ionic
☐ Giant covalent
☐ Simple covalent

☐ Giant metallic

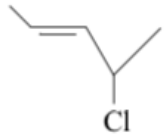
What type of compound is ethyl propanoate?

☐ Aldehyde
☐ Ester
☐ Alcohol
☐ Ketone

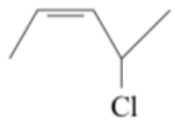
Which of the following compounds is a Z isomer and contains a chiral carbon atom?

☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

☒ **A**



☒ **B**



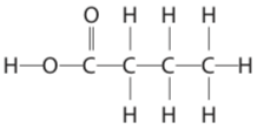
☒ **C**

☒ **D**

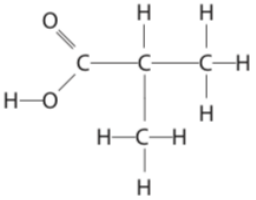
Propanoic acid reacts with methanol to form an ester. The structure of the ester that is formed from both propanoic acid and methanol is?

☐ Molecule A
☐ Molecule B
☐ Molecule C
☐ Molecule D

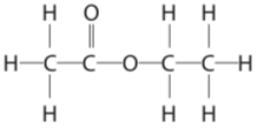
☒ **A**



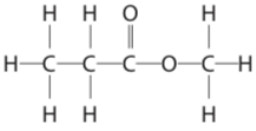
☒ **B**



☒ **C**



☒ **D**



Biology and Chemistry Post-Quiz

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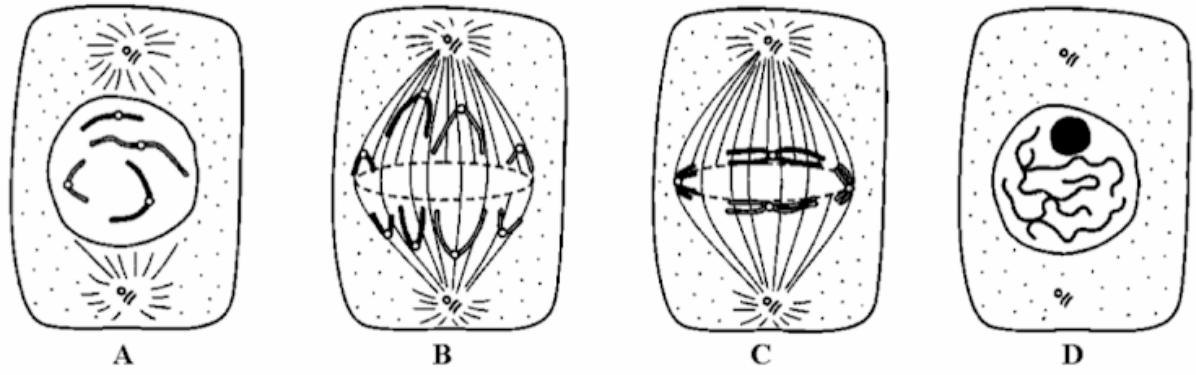
The diagram below shows a cell at four different stages in mitosis. Which of the options below shows the correct sequence in which these four stages occur?



☐ D, A, C, B
☐ A, D, C, B
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Amylopectin is a complex carbohydrate found in the plants. It is similar to glycogen in that it is made up of glucose monomers with the same chain bonding. Which of the following statements is/are true?

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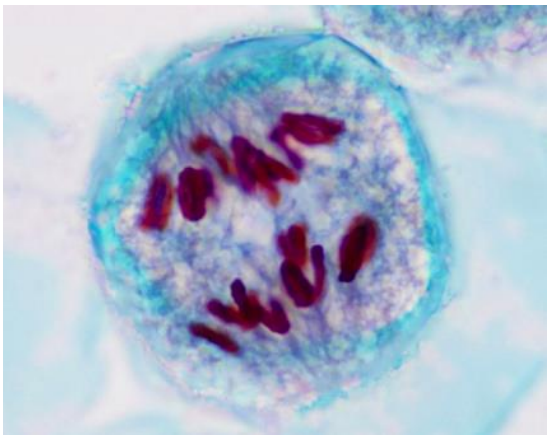
The image below shows an animal cell undergoing mitosis. Which stage of mitosis is shown in the image below?



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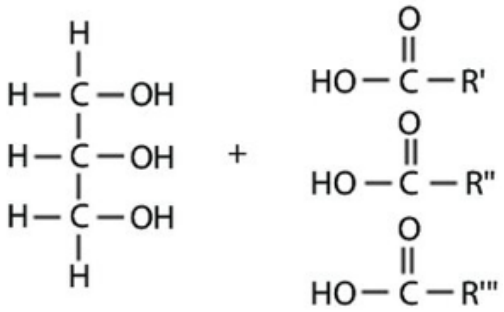

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☐ A condensation reaction forming an ester bond
☐ A hydrolysis reaction forming an ester bond
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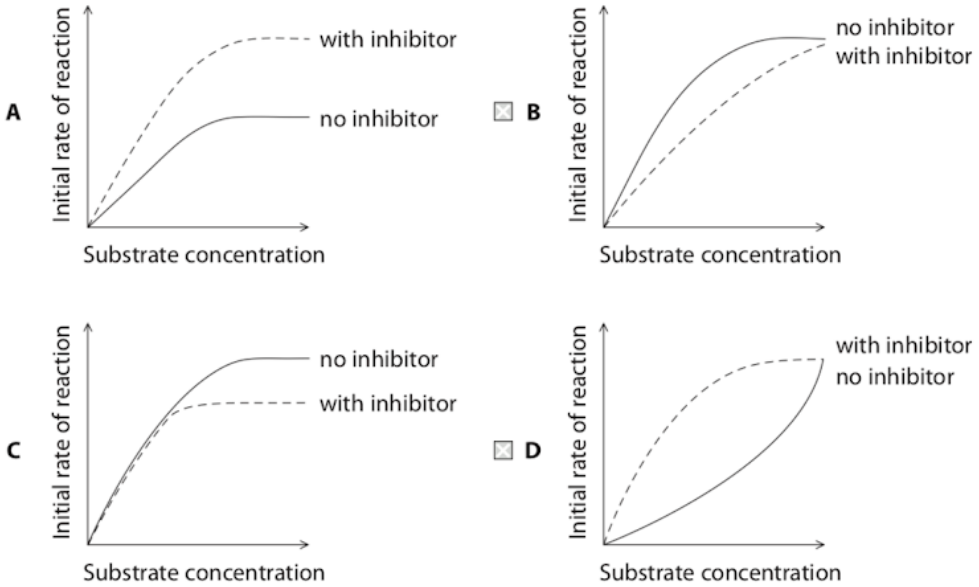

☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

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☐ Statement 1, 2 and 3
☐ Statement 2 and 3
☐ Statement 1 and 3

Carbohydrates, such as glycogen are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of glycogen together?
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Ester
Glycosidic
Peptide

A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence

	Complementary DNA sequence	mRNA sequence
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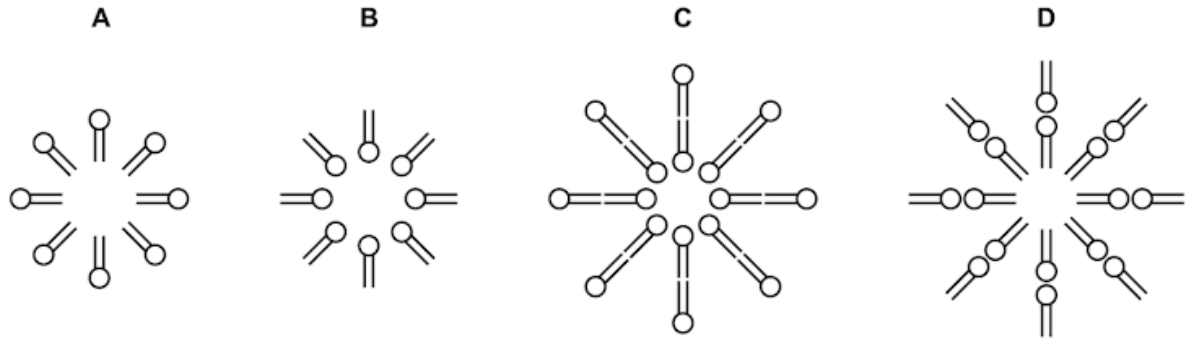
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

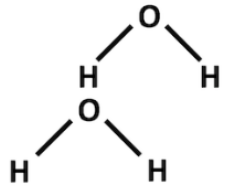
☐ Row A
☐ Row B
☐ Row C
☐ Row D

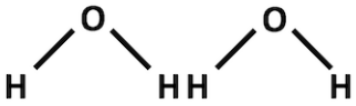
When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution

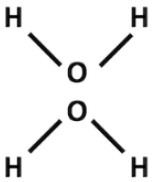


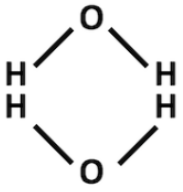
☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following is the most likely way that two water molecules will interact?

Ⓐ 

Ⓑ 

Ⓒ 

Ⓓ 

☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following formulae are NOT representations of saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

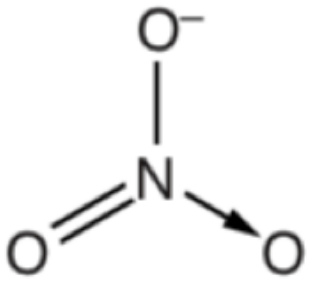
☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

For which of the compounds below are cis-trans isomers possible?

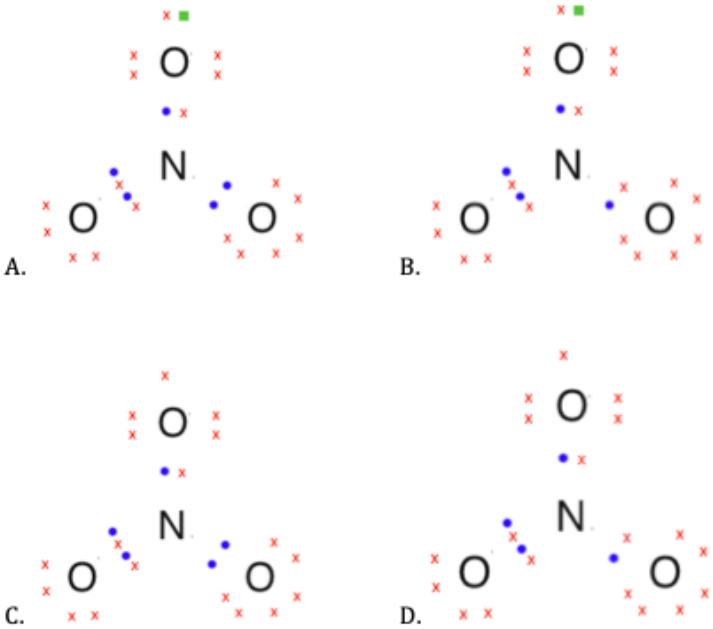
1) $CH_3CH=CH_2$ 2) $CH_3CH=CHCH_2CH_3$ 3) $CH_3CH=CHCH_3$

☐ Only 2
☐ Both 1 and 2
☐ Both 2 and 3
☐ 1, 2 and 3

$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.



Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.



☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of these molecules has a trigonal planar shape?

☐ NH_3
☐ BF3
☐ BeH_2
☐ H_2O

The Properties of elements and their compounds are determined by their structure and bonding. Silicon Dioxide (silica) is very hard and strong with a high melting point. which of the following is the best description of its structure and bonding?

☐ Giant ionic
☐ Giant covalent
☐ Simple covalent
☐ Giant metallic

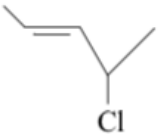
What type of compound is ethyl propanoate?

☐ Aldehyde
☐ Ester
☐ Alcohol
☐ Ketone

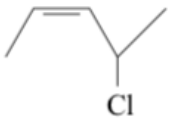
Which of the following compounds is a Z isomer and contains a chiral carbon atom?

☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

☒ **A**



☒ **B**



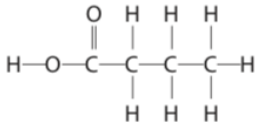
☒ **C**

☒ **D**

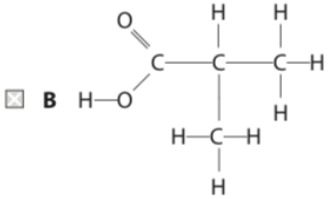
Propanoic acid reacts with methanol to form an ester. The structure of the ester that is formed from both propanoic acid and methanol is?

☐ Molecule A
☐ Molecule B
☐ Molecule C
☐ Molecule D

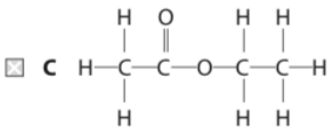
☒ **A**



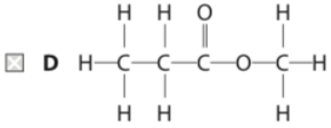
☒ **B**



☒ **C**



☒ **D**



Appendix 42 – MPharm main study pre-quiz

An Evaluation of An Augmented Reality learning tool in Academic Education

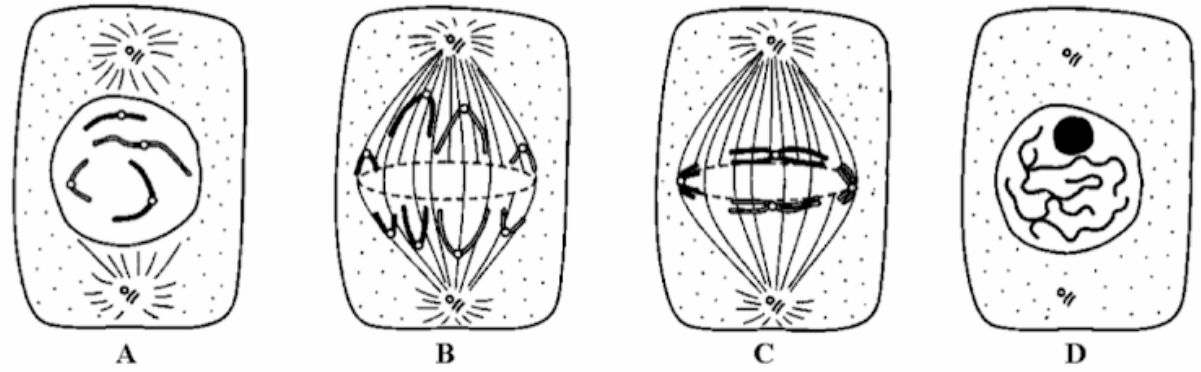
Please provide the same email address you used in the previous stages of the study

Pre-Quiz

Sucrose is formed from the reaction between glucose and fructose. Both have the chemical formula $C_6H_{12}O_6$. What is the chemical formula of sucrose?

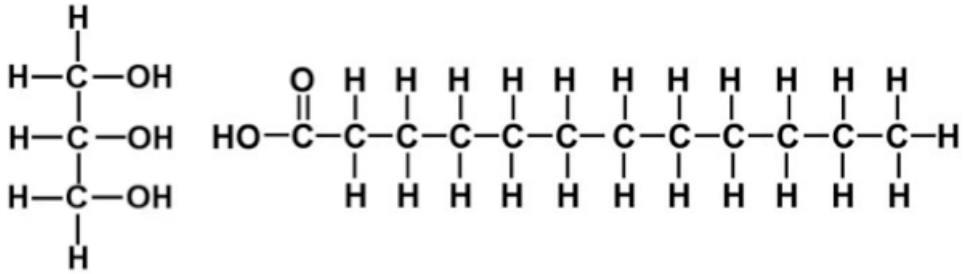
☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{22}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{11}$

The diagram below shows a cell at four different stages in mitosis. Which of the options below shows the correct sequence in which these four stages occur?



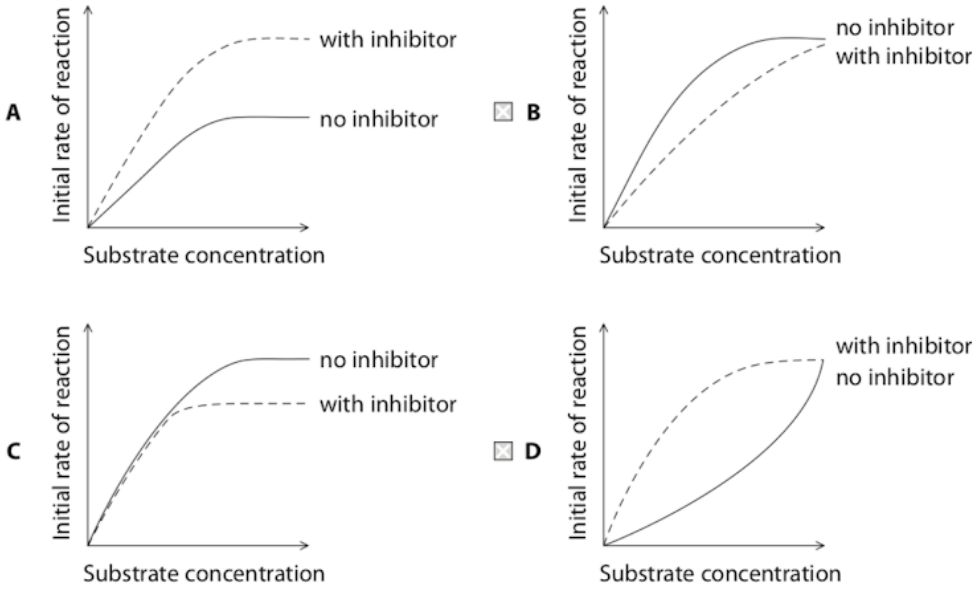
☐ D, A, C, B
☐ A, D, C, B
☐ D, A, B, C
☐ A, B, C, D

Glycerol and fatty acid molecules are used in the synthesis of cell membranes. which of the statements below describes the reaction when these two molecules join together?



☐ A condensation reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond
☐ A hydrolysis reaction forming an ester bond
☐ A hydrolysis reaction forming a glycosidic bond

Succinate dehydrogenase is an enzyme found in mitochondria. Succinate dehydrogenase converts succinate to fumarate. The enzyme's activity is competitively inhibited by malonate. Which of the graphs represents the effect of this type of inhibitor?



☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

Carbohydrates, such as starch are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of starch together?

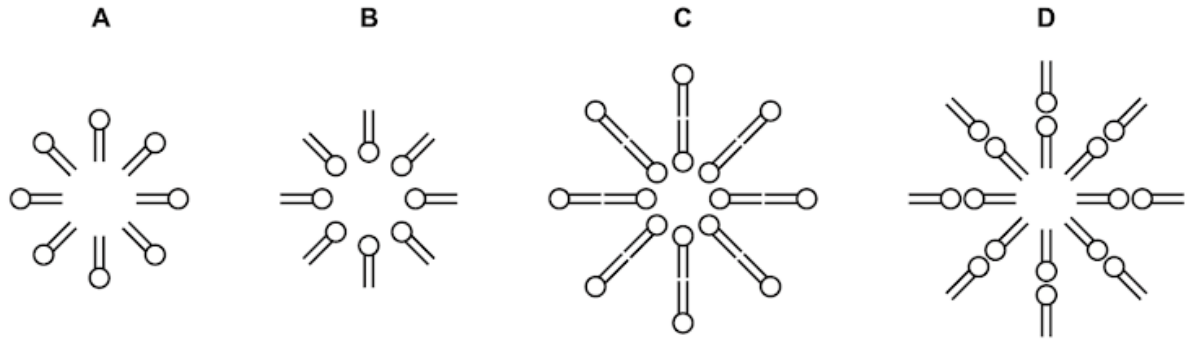
☐ Phosphodiester
☐ Ester
☐ Glycosidic
☐ Peptide

A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence

	Complementary DNA sequence	mRNA sequence
A	AATCGCGGTCGCTCA	UUAGCGCCAGCGAGU
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

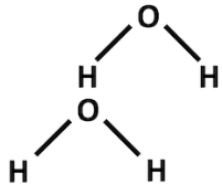
☐ Row A
☐ Row B
☐ Row C
☐ Row D

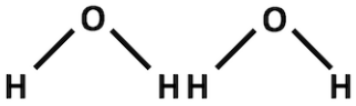
When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution

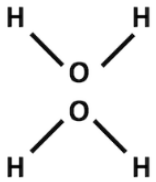


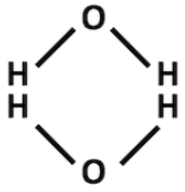
☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following is the most likely way that two water molecules will interact?

Ⓐ 

Ⓑ 

Ⓒ 

Ⓓ 

☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

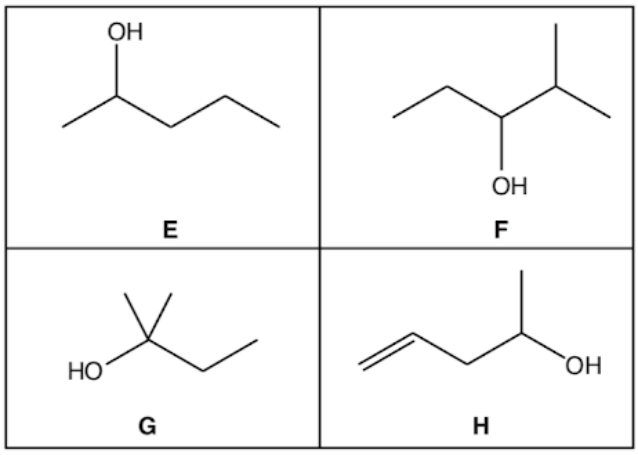
Which of the following formulae represents a saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

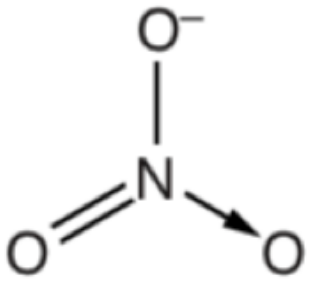
☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

The skeletal formulae of four alcohols are shown below. Which pair are structural isomers of one another?

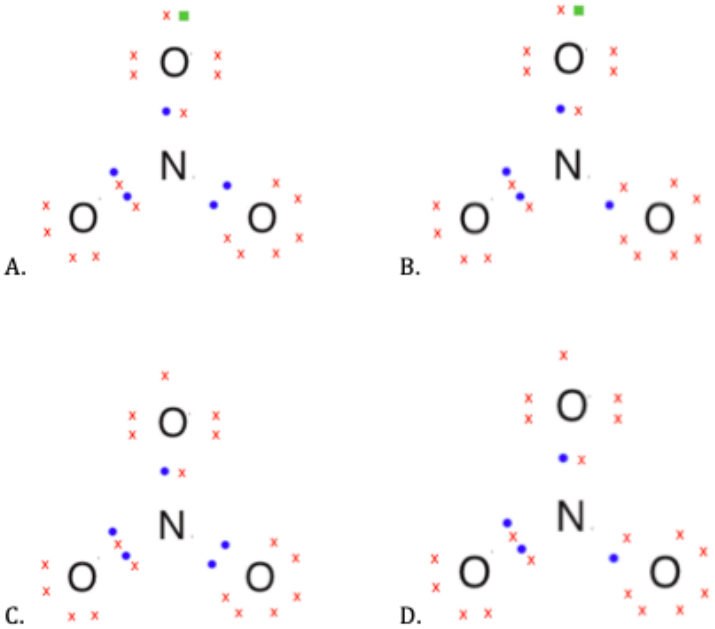
☐ E and F
☐ E and G
☐ E and H
☐ F and G



$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.



Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.

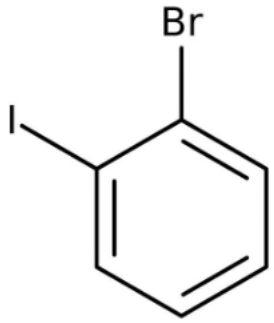


☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of these molecules has a tetrahedral shape?

☐ H_2O
☐ NH_4^+
□ BF_3
☐ NH^3

How many signals are expected in the decoupled 13C NMR spectrum of 1-bromo-2-iodobenzene?

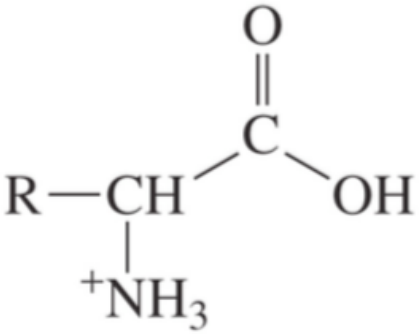


☐ 2
☐ 3
☐ 5
☐ 6

What type of compound is ethyl ethanoate?

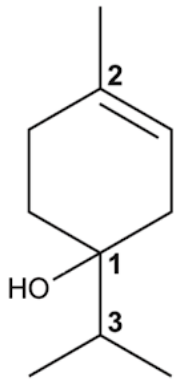
☐ Aldehyde
☐ Ester
☐ Alcohol
☐ Ketone

Zwitterions are compounds which are both bases and acids depending on the pH of the environment. A zwitterion with a carboxyl pKa of 3.2 and amine pKa of 9.1 will have the below structure at what pH?



☐ pH 1
☐ pH 4
☐ pH 7
☐ pH 9

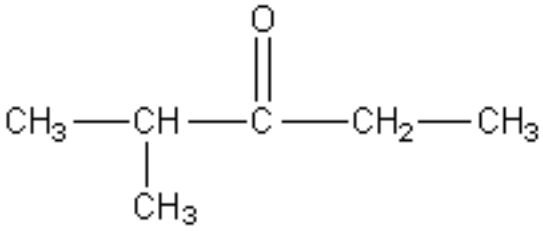
One of the active ingredients in tea area oil is terpinen-4-ol. In the diagram of skeletal formula of terpinen-4-ol, three of the carbon atoms are labelled 1, 2 and 3. Which of the labelled carbon atoms are chiral?



terpinen-4-ol

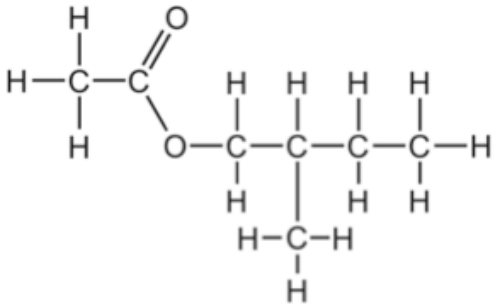
☐ Atom 1
☐ Atom 2
☐ Atom 3
☐ Atoms 1, 2 and 3

How many signals are expected in the decoupled 13C NMR spectrum of isopropyl ketone?



☐ 3
☐ 4
☐ 5
☐ 6

Bees use 2-methylbutyl ethanoate as an 'alarm' pheromone to alert other bees



2-methylbutyl ethanoate

Which starting material would be required to synthesis 2-methylbutyl ethanoate?

A. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CO_2H$
B. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2OH$
C. CH_3CH_2OH and $CH_3CH_2CH(CH_3)CH_2CO_2H$
D. CH_3CO_2H and $CH_3CH_2CH(CH_3)CH_2CO_2H$

☐ Molecules A
☐ Molecules B
☐ Molecules C
☐ Molecules D

For which of the compounds below are cis-trans isomers possible?

1) $CH_3CH=CH_2$ 2) $CH_3CH=CHCH_2CH_3$ 3) $CH_3CH=CHCH_3$

☐ Only 2
☐ Both 1 and 2
☐ Both 2 and 3
☐ 1, 2 and 3

Appendix 43 – MPharm main study post-quiz

An Evaluation of An Augmented Reality learning tool in Academic Education

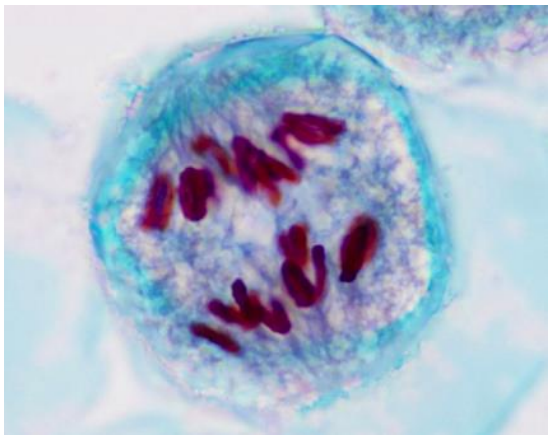
Please provide the same email address you used in the previous stages of the study

Post-Quiz

Lactose is formed from the reaction between glucose and galactose. Both have the chemical formula C6H12O6. What is the chemical formula of Lactose?

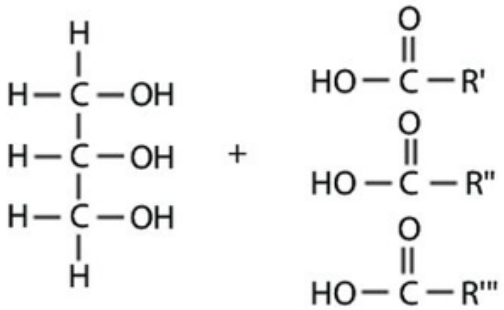
☐ $C_{12}H_{26}O_{13}$
☐ $C_{12}H_{22}O_{22}$
☐ $C_{12}H_{24}O_{12}$
☐ $C_{12}H_{22}O_{11}$

The image below shows an animal cell undergoing mitosis. Which stage of mitosis is shown in the image below?



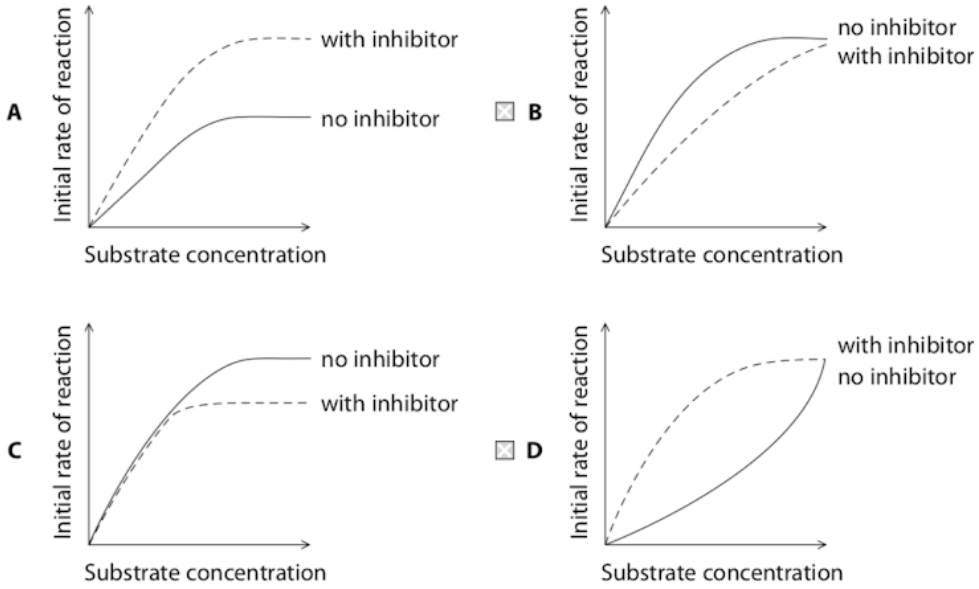
☐ Anaphase
☐ Metaphase
☐ Prophase
☐ Telophase

Glycerol and fatty acid molecules are used in the synthesis of triglycerides. which of the statements below describes the reaction when these two molecules join together?



☐ A hydrolysis reaction forming a glycosidic bond
☐ A condensation reaction forming an ester bond
☐ A hydrolysis reaction forming an ester bond
☐ A condensation reaction forming a glycosidic bond

Dihydropteroate synthase is an enzyme found in humans that contributes to the production of folic acid. The enzyme's activity is competitively inhibited by a drug called Sufanilamide. Which of the graphs represents the effect if this type of inhibitor?



☐ Graph A
☐ Graph B
☐ Graph C
☐ Graph D

Carbohydrates, such as glycogen are made from monosaccharides joined together. Which of the bonds below joins the monosaccharides of glycogen together?

☐ Phosphodiester
☐ Ester
☐ Glycosidic
☐ Peptide

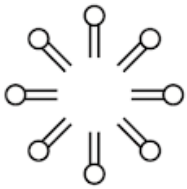
A length of DNA has the sequence AATCGCGGTCGCTCA. Select the row that shows the correct complementary DNA strand and the sequence of mRNA made during transcription of the DNA sequence

	Complementary DNA sequence	mRNA sequence
A	AATCGCGGTCGCTCA	UUAGCGCCAGCGAGU
B	TTAGCGCCAGCGAGT	UUAGCGCCAGCGAGU
C	TTAGCGCCAGCGAGT	TTAGCGCCAGCGAGT
D	TTAGCGCCAGCGAGT	AAUCGCGGUCGCUCA

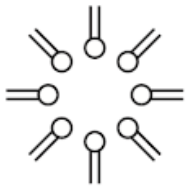
☐ Row A
☐ Row B
☐ Row C
☐ Row D

When a small quantity of phospholipid is added to a test-tube of water and then shaken vigorously, an emulsion is formed by small droplets called liposomes. Which diagram shows the arrangements of phospholipid molecules in a cross-section of a liposome in an aqueous solution

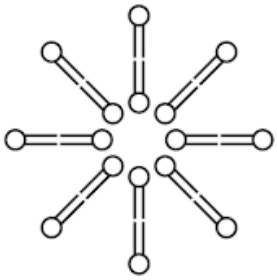
A



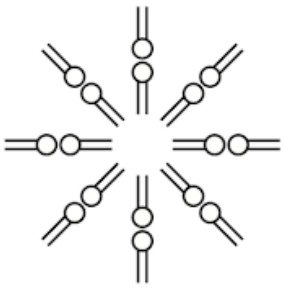
B



C

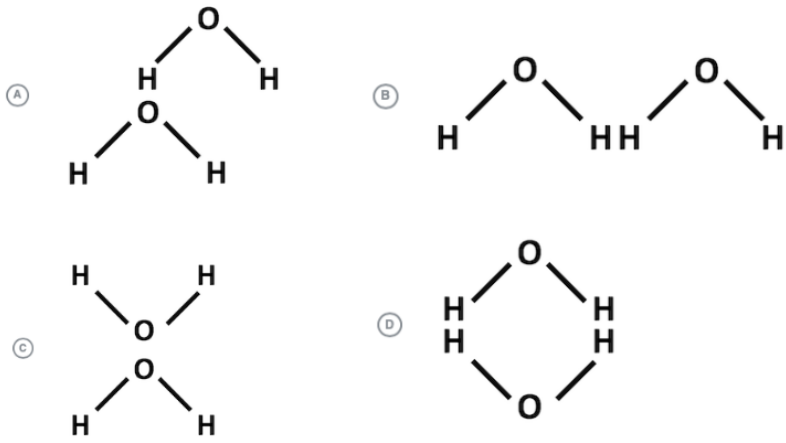


D



☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following is the most likely way that two water molecules will interact?



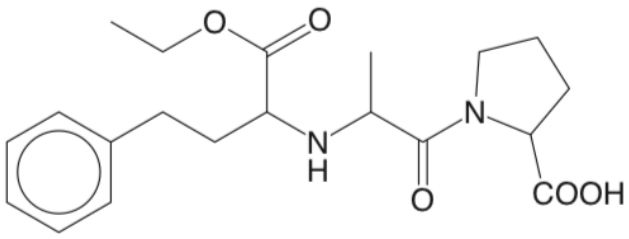
☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of the following formulae are NOT representations of saturated fatty acid?

Statement 1: Palmitic acid $C_{15}H_{31}COOH$
Statement 2: Oleic acid $C_{17}H_{33}COOH$
Statement 3: Linoleic acid $C_{17}H_{31}COOH$

☐ 1
☐ 1 and 2
☐ 2 and 3
☐ 1, 2 and 3

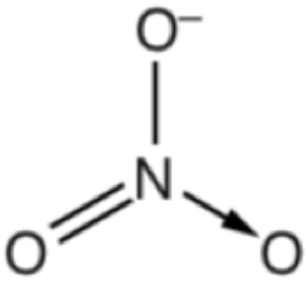
The structure of Enalapril is shown below. How many chiral centres can be found in the chemical structure of enalapril?



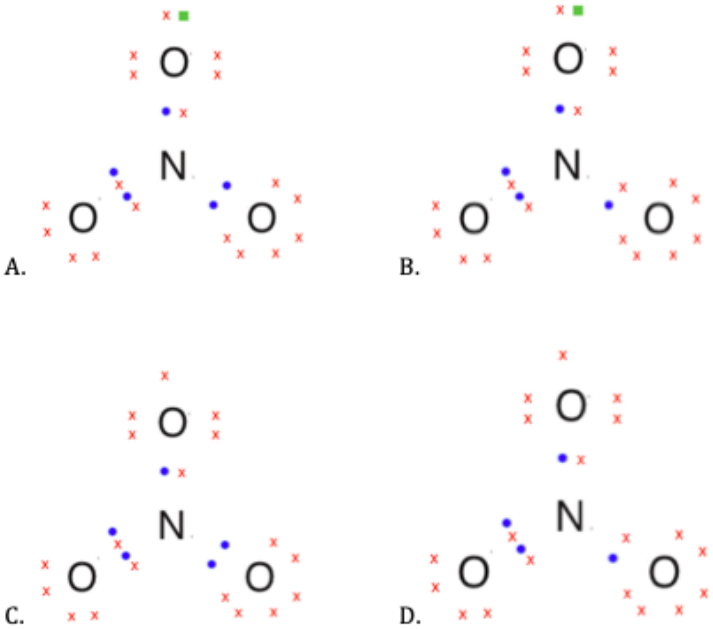
enalapril

☐ 3
☐ 4
☐ 5
☐ 6

$Ni(NO_3)_2$ contains the NO^{3-} ion. The nitrogen atom bonds to the oxygen atoms with a single covalent bond, a double covalent bond and a dative covalent bond as shown below.



Which dot and cross diagram showing only the outer electrons correctly represents the NO_3^- ion.

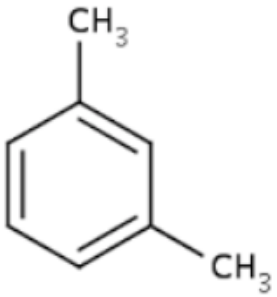


☐ Diagram A
☐ Diagram B
☐ Diagram C
☐ Diagram D

Which of these molecules has a trigonal planar shape?

☐ NH_3
☐ BF3
☐ BeH_2
☐ H_2O

How many signals are expected in the decoupled 13C NMR spectrum of 1,3-Dimethylbenzene?

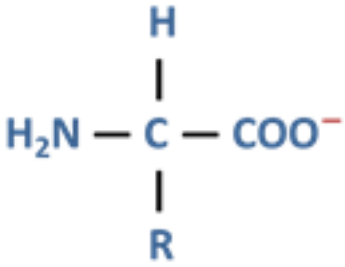


- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8

What type of compound is methyl propanoate?

- ☐ Aldehyde
- ☐ Ester
- ☐ Alcohol
- ☐ Ketone

Zwitterions are compounds which are both bases and acids depending on the pH of the environment. A zwitterion with a carboxyl pKa of 3.2 and amine pKa of 9.1 will have the below structure at what pH?

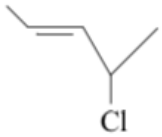


- ☐ pH 1
- ☐ pH 4
- ☐ pH 9
- ☐ pH 11

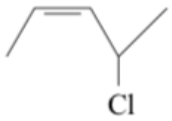
Which of the following compounds is a Z isomer and contains a chiral carbon atom?

- ☐ Diagram A
- ☐ Diagram B
- ☐ Diagram C
- ☐ Diagram D

☒ **A**



☒ **B**

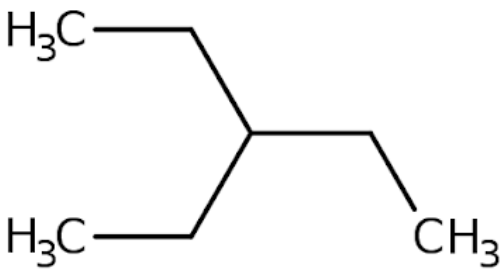


☒ **C**

☒ **D**

How many signals are expected in the decoupled 13C NMR spectrum of 3-Ethylpentane?

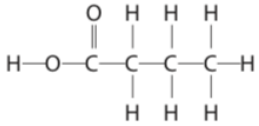
☐ 1
☐ 3
☐ 5
☐ 7



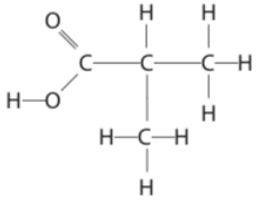
Propanoic acid reacts with methanol to form an ester. The structure of the ester that is formed from both propanoic acid and methanol is?

☐ Molecule A
☐ Molecule B
☐ Molecule C
☐ Molecule D

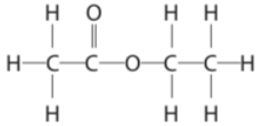
☒ **A**



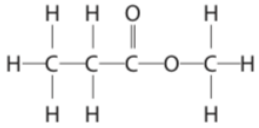
☒ **B**



☒ **C**



☒ **D**



For which of the compounds below are cis-trans isomers NOT possible?

1) $CH_3CH=CH_2$ 2) $CH_3CH=CHCH_2CH_3$ 3) $CH_3CH=CHCH_3$

☐ Only 1
☐ Both 1 and 2
☐ Both 2 and 3
☐ 1, 2 and 3

Appendix 44 – Main study interview protocol

Semi-Structured Interview Guide

Protocol

- Participants are welcomed and asked to confirm both their identity and provide verbal consent to the interview
- The lead researcher will introduce the objectives of the interview and explain the nature of the questions
- Participants will be reminded that the interview will be recorded (audio only) for research purposes and that the recording will be transcribed, and dialogue made anonymous
- Participants will be informed that quotes may be taken from the transcribed dialogue and used in publications and reports surrounding the research project
- Participants will be informed that the quotes used will be anonymised before they are used in publications and reports

Student Semi-Structured Interview Guide

Pre-intervention Period

1. What specifically about your preferred styles of learning did you enjoy the most? (1)
2. How confident do you feel with your preferred style of learning? (1)
3. Prior to the AR learning tool what would you say gave you the greatest motivational drive to learn?

Intervention period and post intervention period

1. What were your initial thoughts on the Pharma Compounds learning tool before its use? (2,4)
2. As time went on, did those thoughts change? If so, how? (4)
3. How did you imagine it would fit into your current learning routine? (6)
4. Could you explain how you used the learning tool during your studies? (5,7,8,9)
5. Did the AR tool help you understand/develop or re-enforce certain topic areas? (2)
6. Would you use a similar learning tool in other aspects of your learning? (7,8, 14)
7. Would this learning tool benefit students in other year groups? (14)
8. Do you feel as though the AR tool provided a viable support option for your learning? (13, 14,15)
9. Is there any other way you feel the learning tool could have supported your learning? (14,15)
10. Were there any specific cards that you found most useful during your learning? (14,15)
11. How would you describe your attitude and motivation towards learning when using the Pharma Compounds learning tool? (13, 14, 16)
12. Did your use of the AR learning tool change as time went on? (8, 14,15)
13. Do you think your attitudes and motivation in other subject areas would change if you were introduced to similar types of learning tools for those areas? (7, 8, 13,14)
14. Do you feel any changes made to the learning tool could improve your motivation towards your learning?

15. What challenges did you encounter with the use of the Pharma Compounds learning tool?
16. What about the AR learning tool could be improved?
17. What would be the ideal way to use the AR learning tool according to you? (14)

Tutor Semi-structured Interview Guide

Pre-Intervention Period

1. What styles of teaching do you think your students enjoy the most? (1)
2. How confident do you feel they are when learning in that way?
3. Prior to your students using the AR learning tool, what would you say gave your students the greatest motivational drive to learn?

Intervention Period and Post-Intervention Period

1. What were/are your initial thoughts on the Pharma Compounds learning tool? (2,4)
2. As time went on, did those thoughts change? If so, how? / How do you think your thoughts on the learning tool will change over time? (6)
3. How did you/do you imagine it would fit into your current teaching sessions? (5, 7, 8, 9)
4. Could you explain how you actually used the learning tool during your teaching sessions? (5, 7, 8, 9)
5. Did/do you think the AR tool help your students understand/develop or re-enforce certain topic areas? (2)
6. Would you be prepared to use a similar learning tool in more of your teaching sessions? (7, 8, 14)
7. Would this learning tool with its current content help students in other year groups? (14)
8. Do you feel as though an AR learning tool can provide a viable educational support option for your students learning? (13, 14, 15)
9. Is there any other way you feel the learning tool could support your students learning? (14, 15)
10. Are there any specific cards that you think your students found useful in there learning? (14, 15)
11. How would you describe your students' attitude and motivation towards learning when they using the Pharma Compounds learning tool? (13, 14, 16)
12. Did the use of the AR learning tool in you teaching sessions change as time went on? (8, 14, 15)
13. How do you think your students' attitudes and motivation in other subject areas? (7, 8, 13, 14)
14. Do you feel any changes made to the learning tool could help improve your students' motivation in your teaching sessions?
15. What challenges did you/do you think you will encounter with the use of the Pharma Compounds learning tool?
16. What about the AR learning tool could be improved?
17. What would be the ideal way to use the AR learning tool according to you? (14)

Appendix 45 – Sixth Form Individual IMI Likert Agreement Scores

The table below displays the individual IMI Likert agreement scores for sixth form participants who completed pre- and post-intervention questionnaires. The scale featured seven points; point 1 - Not true at all, point 4 - Neither, and point 7 - Very true.

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
A1	Pre	4	7	4	4	4	4	4	4	4	4	-	-	-	-
	Post	4	5	6	5	5	2	5	3	6	5	6	5	4	6
A2	Pre	4	4	5	3	4	5	4	4	4	3	-	-	-	-
	Post	4	3	2	4	2	2	3	4	2	5	5	2	1	1
A4	Pre	3	2	4	3	4	4	3	6	3	3	-	-	-	-
	Post	5	4	5	6	5	2	5	2	6	6	6	6	6	6
A7	Pre	5	4	6	6	6	2	5	2	4	6	-	-	-	-
	Post	1	1	5	5	6	3	1	2	7	1	7	3	6	5
A23	Pre	4	4	5	3	4	2	4	2	4	4	-	-	-	-
	Post	5	4	5	5	5	3	5	3	5	5	5	5	5	5
A24	Pre	4	4	4	4	4	2	4	4	3	4	-	-	-	-
	Post	2	2	3	3	3	5	3	4	5	3	5	5	4	3
A28	Pre	6	5	6	4	5	2	5	2	6	6	-	-	-	-
	Post	5	5	5	7	6	2	5	1	5	5	7	4	6	6
A35	Pre	5	1	5	3	6	2	4	4	1	4	-	-	-	-

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	Post	4	4	6	4	6	3	4	3	7	4	7	6	7	4
A48	Pre	5	2	7	4	7	5	4	3	1	4	-	-	-	-
	Post	5	5	4	5	6	2	6	2	6	6	7	7	6	7
A49	Pre	5	3	5	4	6	3	4	4	5	5	-	-	-	-
	Post	5	3	5	6	5	4	5	2	6	6	7	5	6	7
A50	Pre	7	6	7	6	7	2	6	3	6	6	-	-	-	-
	Post	5	4	3	5	5	2	5	1	5	6	7	5	5	6
A51	Pre	5	5	7	5	5	5	5	6	5	5	-	-	-	-
	Post	2	3	2	5	3	3	6	3	2	5	7	2	2	2
A52	Pre	6	4	5	5	5	2	5	2	5	5	-	-	-	-
	Post	5	5	3	5	3	2	5	2	5	5	6	2	4	5
A53	Pre	3	2	4	4	5	4	3	5	4	4	-	-	-	-
	Post	5	4	4	6	4	2	5	3	4	4	6	3	5	4
A55	Pre	6	4	6	5	6	6	4	4	6	5	-	-	-	-
	Post	6	4	5	5	6	2	6	2	3	6	2	5	6	7
A56	Pre	6	5	7	6	7	1	6	1	5	6	-	-	-	-
	Post	7	6	6	7	7	1	7	1	7	7	7	7	7	7
A57	Pre	6	4	6	5	6	2	6	2	7	6	-	-	-	-

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	Post	6	5	7	7	7	2	7	2	6	7	7	7	7	6
A58	Pre	4	3	5	3	6	6	4	5	4	4	-	-	-	-
	Post	5	4	5	5	5	3	5	2	5	5	6	5	6	6
A59	Pre	2	2	2	2	3	2	2	5	3	3	-	-	-	-
	Post	6	6	6	6	5	2	5	2	5	5	6	6	5	5
A60	Pre	4	2	6	4	6	2	2	4	4	4	-	-	-	-
	Post	6	5	6	6	6	1	6	1	6	6	7	6	6	6
A61	Pre	6	4	6	5	6	1	5	2	7	5	-	-	-	-
	Post	5	5	5	5	5	2	5	1	7	6	5	5	7	5
A62	Pre	4	3	6	3	6	5	3	5	2	2	-	-	-	-
	Post	6	6	4	6	5	2	7	1	6	6	5	4	5	5
A64	Pre	4	1	7	2	6	2	1	7	7	4	-	-	-	-
	Post	7	7	7	6	7	7	7	2	7	7	7	7	7	7

Appendix 46 – MPharm Student Individual IMI Likert Agreement Scores

The table displays the individual IMI Likert agreement scores for undergraduate participants who completed pre- and post-intervention questionnaires. The scale featured seven points, point 1 - Not true at all, point 4 - Neither, and point 7 - Very true

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
B1	Pre	5	2	7	5	7	1	4	6	4	5	-	-	-	-
	Post	5	3	5	5	5	1	5	2	5	4	5	4	3	5
B2	Pre	3	4	4	3	5	4	2	5	3	3	-	-	-	-
	Post	5	4	5	5	6	3	6	2	5	6	6	4	5	5
B3	Pre	7	7	7	7	7	7	7	7	7	7	-	-	-	-
	Post	5	5	2	6	4	1	4	1	7	6	6	6	6	5
B4	Pre	5	4	5	4	5	3	3	4	4	4	-	-	-	-
	Post	4	4	5	6	3	4	3	2	4	5	6	4	5	5
B5	Pre	5	3	4	3	5	4	2	6	5	3	-	-	-	-
	Post	5	4	6	6	6	3	6	3	5	5	5	5	5	5
B6	Pre	5	3	6	4	5	3	4	5	5	5	-	-	-	-
	Post	3	1	4	6	6	4	6	3	5	5	7	5	5	4
B7	Pre	5	3	6	4	6	2	4	3	4	4	-	-	-	-
	Post	6	5	4	6	6	2	6	3	6	6	5	3	6	6
B8	Pre	3	3	4	3	4	4	4	4	4	3	-	-	-	-

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Post	5	4	5	5	5	2	5	2	5	5	5	5	5	5
B9	Pre	5	4	4	3	5	5	4	5	7	4	-	-	-	-
	Post	5	5	5	4	4	4	4	3	6	5	6	4	5	5
B15	Pre	4	4	4	4	4	4	4	4	4	4	-	-	-	-
	Post	4	4	4	4	4	4	4	4	4	4	4	4	4	4
B18	Pre	4	4	5	4	5	3	4	3	4	3	-	-	-	-
	Post	6	6	7	7	7	1	7	1	7	6	7	7	7	6
B20	Pre	3	3	5	2	3	3	2	6	4	3	-	-	-	-
	Post	6	5	6	5	7	2	7	1	6	6	6	6	7	6
B21	Pre	3	1	5	1	5	5	2	6	5	3	-	-	-	-
	Post	5	3	5	5	5	2	5	3	6	6	6	4	6	5
B22	Pre	4	3	4	4	5	6	3	5	4	4	-	-	-	-
	Post	6	5	5	7	6	3	6	3	5	5	6	5	6	6
B23	Pre	3	4	3	3	4	5	4	5	4	3	-	-	-	-
	Post	5	4	6	7	6	3	6	3	6	6	7	6	6	5
B24	Pre	3	1	4	4	5	3	6	3	6	4	-	-	-	-
	Post	7	3	5	5	5	4	5	3	6	5	6	4	5	5
B26	Pre	5	4	6	4	5	3	3	3	3	5	-	-	-	-

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Post	4	3	3	5	6	4	6	2	4	4	4	3	5	4
B29	Pre	5	5	4	4	4	4	4	4	4	4	-	-	-	-
	Post	4	4	4	4	4	4	4	4	6	6	4	4	4	4
B31	Pre	4	2	6	5	5	2	2	4	3	3	-	-	-	-
	Post	5	3	4	6	6	3	6	3	7	5	6	4	5	5
B32	Pre	4	5	4	3	5	3	4	2	5	4	-	-	-	-
	Post	6	6	6	7	7	1	7	1	7	7	7	7	7	7
B35	Pre	4	3	4	4	4	2	3	5	4	4	-	-	-	-
	Post	2	2	3	4	2	5	2	4	3	2	4	2	2	2
B39	Pre	4	1	5	2	6	3	3	5	5	3	-	-	-	-
	Post	4	3	7	6	6	3	6	3	7	6	7	7	6	6
B41	Pre	7	7	7	3	7	1	5	6	7	6	-	-	-	-
	Post	4	6	6	7	7	1	7	3	7	7	7	7	7	6
B44	Pre	3	1	5	3	4	4	3	5	3	3	-	-	-	-
	Post	3	1	3	4	3	4	3	3	3	3	4	3	3	4
B49	Pre	2	3	3	3	3	4	2	5	3	5	-	-	-	-
	Post	5	4	6	6	7	1	7	2	5	5	5	5	7	5
B55	Pre	6	6	6	6	6	6	6	6	6	6	-	-	-	-

Participant	Questionnaire	Intrinsic motivation inventory statement													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Post	5	5	5	6	6	6	6	5	5	6	6	6	6	6
B58	Pre	6	7	7	5	7	2	6	2	6	6	-	-	-	-
	Post	6	5	6	6	6	1	6	1	4	6	7	6	6	6
B63	Pre	6	4	6	5	6	3	6	2	5	5	-	-	-	-
	Post	5	4	3	6	5	4	5	3	5	5	6	4	4	4
B66	Pre	6	3	6	4	5	2	2	4	6	5	-	-	-	-
	Post	7	5	7	6	7	1	7	1	6	7	7	7	7	7
B68	Pre	7	4	6	2	6	1	2	5	6	5	-	-	-	-
	Post	6	5	6	6	6	1	6	1	7	5	7	6	6	6