Article:

Web-based student response systems and peer instruction: a review and case study

Short title: Student Response Systems and peer instruction

Cinzia Cervato

Doctor of Science, Morrill Professor of Geological and Atmospheric Sciences

Iowa State University, 253 Science I, Ames, IA 50011, USA, cinzia@iastate.edu

Phone: +1-515-294-7583

ILAS Fellow, Keele University, spring 2019

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Abstract

Cooperative learning and peer instruction are well documented pedagogies that engage students in their learning process. The means to implement cooperative learning in the classroom have evolved from raised hands, colored flashcards, student response systems or "clickers", to web-based audience response systems that work on any electronic device. This paper briefly reviews available audience response systems and presents a case study on Learning Catalytics, a system designed to enable peer instruction and implement just-in-time teaching pedagogy.

Keywords

Context

Liberal arts education is the foundation of Western education, and advocates for a curriculum that includes the study of arts and humanities, social sciences, mathematics, and natural sciences. Deeply rooted in the educational system in Europe, liberal arts education is at the foundation of higher education in the United States. This means that a student pursuing a four-year Bachelor of Science or Bachelor of Arts degree will earn between one third to one half of the credits required to graduate through general education courses in each of the four liberal arts components. The remainder of the credits will be focused on the major discipline in which they are earning their degree, and ancillary courses required for the major (chemistry, physics, mathematics, English).

These general education requirements are usually fulfilled by attending introductory level courses in a range of disciplines, from sociology to psychology, from American Indian studies to women studies, and from biology to astronomy, where the vast majority of students are not pursuing a degree in the discipline of the course. As a result, the challenge for the instructor is to engage these students in a content in which they might have little interest.

At large public universities with enrollment in the tens of thousands, these general education courses have often enrollments of hundred or even thousand students, ranging from first-year students directly out of high-school, non-traditional students returning to college after working or a career in the military, to graduating seniors. Extensive research shows that active learning techniques are more effective at engaging students and increasing learning, particularly non-science majors in science courses (PCAST, 2012; Prince, 2004; Schell et al., 2013). However, 55% of STEM courses in the U.S. are still taught by lecturing, 27% by lecturing with some form of interactivity, and only 18% are fully student-centered (Stains et al., 2018).

Pedagogy

Collaborative and cooperative learning are two pedagogical approaches that encourage students to work in groups (Miller & Groccia, 1997; Prince, 2004). Although the two terms are often used interchangeably, the two approaches differ in the way they assess students: collaborative learning assesses students in groups, whereas cooperative learning assesses them individually (Miller & Groccia, 1997). The most common example of collaborative learning technique is team-based learning (TBL) (Michaelsen et al., 1982; Prince, 2004). There are many ways to implement cooperative learning in the classroom (e.g., McConnell et al., 2017), and the one of the most widely used in STEM courses is peer instruction (Mazur, 1997).

Peer instruction utilises student interactions to focus students' attention and learning on concepts instead of memorization. It uses the ConcepTest approach: first the instructor gives a short lecture about a key point followed by a short, conceptual question about the subject (Mazur, 1997; McConnell et al., 2006; Crouch et al., 2007; McConnell et al., 2017). Students respond first to the question individually. After responding, students are not shown the correct answer. Instead, they discuss or debate their answers with neighbours and answer the question a second time. This is also where students are engaging in cooperative, social learning (McConnell et al., 2006, 2017; Stoltzfus, 2016). These discussions allow students to formulate their ideas in their own words, think through arguments, and provide them with a way to judge their own understanding of the concept (Mazur, 1997; Crouch et al., 2007).

Peer instruction adds variety for the students and the instructor, allows students to put their thoughts into their own words, increases problem-solving skills, understanding of concepts, and engagement. It has been shown to result in higher student grades, it creates social bonds, can correct misconceptions, and improves attitudes toward science (Mazur, 1997; McConnell et al., 2006, 2017; Crouch et al., 2007; Schell et al., 2013). It can be implemented relatively easily, and can be used in classrooms of a variety of sizes.

The goal of this paper is to provide an overview of the most common web-based audience response system technology and to introduce Learning Catalytics™, the student response system technology that most closely implements the peer instruction model. It also briefly describes how it is used to support the Just-In-Time Teaching pedagogy

Learning technology for student engagement

Student Response Systems

The challenge in implementing peer instructions in large enrollment courses is in recording students' answers. When Eric Mazur first introduced peer instruction and ConcepTests in his physics classes at Harvard University in the early 1990s, students used coloured flashcards, with four different colours for four possible answers (Mazur, 1997). Students would place the side with their chosen answer in front of their chest, allowing the instructor to view the colours from the front of the auditorium, but not the rest of the students. When students

were asked to find a partner to discuss their answer, they would be directed to a student with a different colour card (Prud'homme-Generaux, 2017). While this form of formative assessment was pedagogically effective, it did not allow the instructor to record students' answers and give them credit.

Mazur and some of his students developed the first student response system (SRS) to record student answers. Various companies picked up on the concept, and developed SRSs or "clickers" using either infrared or radio frequency technology: the first large and clunky models quickly became the size of small calculators. Their effectiveness as learning tools, but, as importantly, as means to engage students in the classroom, is documented by extensive research (e.g., Fies & Marshall, 2006). However, there are shortcomings in this technology: their implementation is limited to multiple-choice questions, and students or the institution need to purchase the device (~$30 in 2013).

The widespread use of laptops and smartphones pushed the development of response technology that would use laptops and/or smartphones to implement peer instruction without the need of a dedicated device, also opening up the range of types of questions that could be asked.

Web-based audience response systems

There are no fewer than eleven SRSs that can be used with electronic devices like smartphones (Prud'homme-Generaux, 2017). Kahoot (www.kahoot.com) is a game-based learning platform that turns multiple-choice questions into fun learning games that foster social learning by engaging players in 180+ countries. Poll Everywhere (www.polleverywhere.com) and Mentimeter (www.menti.com) are popular with college educators, and allow instructors to poll students during class and conduct formative assessment. Both of them are easy to implement, include a range of possible question types, and include a free version (Nosek, 2017; Prud'homme-Generaux, 2017). They display results in diagrams, word clouds, text answers, and more.

Top Hat, formerly known as TopHatMonocle (www.tophat.com), is a commercial response system created specifically for education, and that allows to record responses by individual students: students use a laptop, tablet, or smartphone to answer questions in class. A comparison of the features of seven of these SRSs is provided by Poll Everywhere (2019) for marketing purposes.

In 2007, Mazur created a web-based audience response system called Learning Catalytics™ (learningcatalytics.com) to fully implement the peer learning pedagogy (Schell et al., 2013). Since 2013, it is marketed by Pearson, a textbook publishing company, but remains independent from their products. While TopHat and Learning Catalytics provide similar features, the fundamental difference between the two SRSs is the ability to dynamically

assign students to groups based on their response available in Learning Catalytics™ (Crouch et al., 2007; Schell et al., 2013, McConnell et al., 2017).

Case study: Learning Catalytics

Since 2001 the author has been teaching introductory physical geology to up to 500 undergraduates each fall semester at Iowa State University. She has experimented with various active learning technologies, including flashcards and clickers. In 2015 she "flipped" the class, developing reading assignments and homework to be completed before each of the three weekly class periods (e.g., Mazur, 1997; Gross et al., 2015; Boevé et al., 2017; Ryan & Reed, 2016; McNally et al., 2017).

The first course within Learning Catalytics™ was developed in summer 2015. It is here that the educator must invest time, creating an extensive database of questions covering the broad curriculum of the course. Each course module designed for each class period pools questions from this database, or from the public pool available through the system. In following semesters, a copy of the original course is created and questions and modules are updated.

At the beginning of the semester, students activate their Learning Catalytics™ account and register for the class. This allows the instructor to record, grade, and give points to all that they will submit throughout the semester.

The class consists of three weekly 50-minute periods over 15 weeks. Students complete assigned readings and an online homework assignment on the readings before each class period. During the first five minutes of class, following announcements and reminders, students submit a written reflection on their readings using Learning Catalytics™. This is done to encourage students to complete their pre-lecture reading assignment. They answer three questions: what was the main topic of the readings, what they found surprising, and what they found confusing.

The instructor is able to view responses as they are submitted, and to take note of the concepts that the students found confusing. To enhance students' motivation to come to class prepared and to attend class, the instructor follows the "Just-in-Time Teaching" approach, and uses the answers to the last question to tailor the class to students' needs (Novak et al., 1999). This is done using Conceptest-style questions drawn from the original pool of questions and collected in a module in Learning Catalytics™ focused on the general topic of the class period. A typical module could include up to 20 questions, and between seven and ten questions would be used in each period. After class, students can access the module and use it for self-test or review the material.

The response type in each course module can be:

1. instructor-led synchronous: students respond to questions individually and at the same time, with an instructor present.
2. Automated synchronous: students respond to questions individually and at the same time as they are delivered automatically; an instructor is usually not present.
3. Self-paced: students respond to questions in any order and outside of class.
4. Self-test: students respond individually to questions and receive feedback on their responses; this is commonly done outside of class and used to prepare for exams.
5. Team-based Assessment: students respond individually to questions and then gather in pre-assigned groups to answer again as a group.

Each module can be scored from 100% participation to 100% correctness, and each question can be given any number of points, including 0.

The type of questions covers a broad range of possibilities, including the ones available in Poll Everywhere and Menti (Table 1), but with more options that are particularly useful in STEM courses.

Table 1: Type and description of questions available in Learning Catalytics, and the availability of each type in Poll Everywhere and Menti marked with X (from Nosek, 2017).

Type of question	Description	Poll Everywhere	Menti
Composite sketch	Students sketch a graph and the results are shown as a composite sketch; this works well in large classes		
Confidence	Students distribute a fixed number of votes on each of the options/answers given based on their confidence in each answer; points can be assigned to the correct answer, or the question can be used to assess opinion		X
Data collection	Students report a numerical value and results are displayed in a histogram with descriptive statistics		
Direction	Students draw an arrow or vector; arrows pointing in the direction and within a predetermined range of the correct arrow are shows as correct		
Expression	Students enter a mathematical expression or equation		
Highlighting	Students highlight words in a passage and the results are shown in a heat map of the text		
Image upload	Students upload an image		
Long answer	Students enter text in a large input box		

Many choices	Students select zero, one or many choices in response to a question; this can be used to collect opinions		
Matching	Students match a series of subquestions with options to create a matrix		X
Multiple choice	Students select one answer	X	X
Numerical	Students enter a numerical value		
Priority	Students prioritize the given choices; there is no correct choice		
Ranking	Students rank a list of items in order	X	
Region	Students click or touch a point on an image; the instructor determines the area of the image that should be considered correct	X	
Short answer	Students enter text in a small input box	X	X
Sketch	Students sketch a graph; each graph is displayed as tile. This format works better for small classes		
Word cloud	Students submit one or more words, and a word cloud is generated based on the frequency of occurrence of each word	X	X
Slide	Students are shown a static slide; no response is required		

When the instructor launches a session, students access it from their device and are asked to enter their seat number. This allows the instructor to view responses as they are submitted either as a list or as a map (Figure 1 and 2). Correct answers are marked in green, and incorrect ones in maroon. If the percentage of correct responses to a specific concept question exceeds 70%, it is considered to be mastered (Mazur, 1997).

Figure 1: example of instructor interface on Learning Catalytics ™. This example is a multiple choice question. The correct answer is in bold in the question, and green in the summary of the two rounds, with the percentage of responses for each option. Round 2 was collected after students were paired with a partner who answered the question differently.

8. multiple choice

The _____ determines the chemical and physical properties of an atom.

A. number of electrons

B. number of protons

C. size of the nucleus

D. size of the valence electron shell

E. electrical charge

Round 1   ✕ 📍
🔴 114 responses, 47% correct

A. 25%
B. 47%
C. 3%
D. 11%
E. 13%

Round 2   ✕ 📍
🔴 109 responses, 68% correct

A. 24%
B. 68%
C. 0%
D. 6%
E. 2%

✔ 5 get it now
✖ 0 still don't get it

Figure 2: seat map for round 2 of the question in Figure 1. Green squares identify students who answers correctly; the maroon ones are incorrect answers, and the letter identifies which answer was chosen. In this example, most students answered correctly, and the most common incorrect answer was A.

The front of the classroom is at the bottom of the map. Instructors create seat maps for their classroom and they become available to other instructors at the same institution who teach in the same classroom and use this technology.
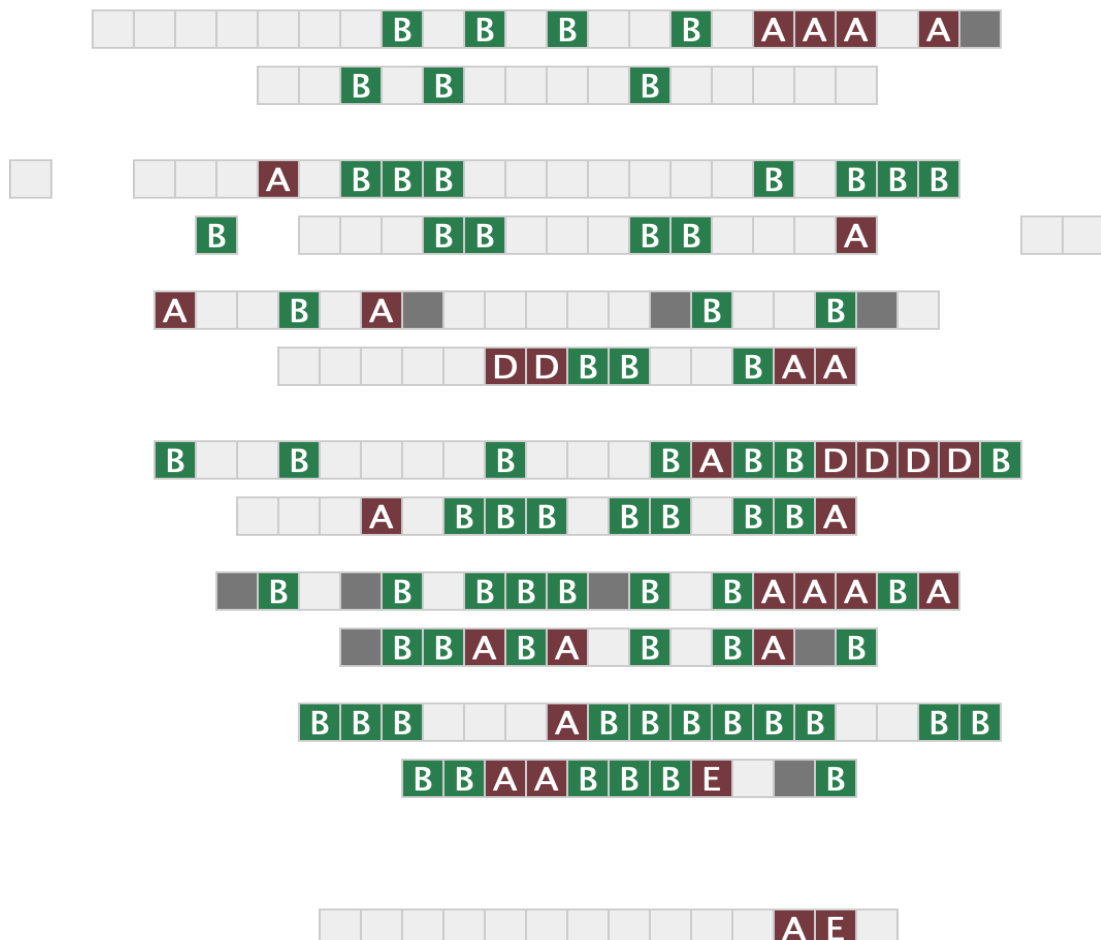
If the percentage of correct responses ranges between 30% and 70%, peer-to-peer matching can be implemented *in situ*: Learning Catalytics™ allows the instructor to determine the parameters of the grouping (e.g., two or more students, within one or two seats, with different answers) before redelivering the question (Figure 1). Each student submits their answer again, and as this happens, the instructor can monitor responses on the seating map (Figure 2). She can choose to approach a group of students with a cluster of incorrect responses and listen to their conversations, or engage them in a discussion based on their chosen answer.

As the questions are delivered, students can ask a question on their device and a window pops up on the instructor's screen; they can also select 'I get it now' or 'I still don't get it' after the correct answer and the distribution of answers is shared (Figure 1). This allows the instructor to answer the question, probe the students' understanding or choose to review the confusing aspects of the concept with a short lecture or demonstration in this or a following class. This approach is recommended when the percentage of correct answers is below 30%, or does not increase significantly after the group discussion.

Discussion

Learning Catalytics™ collects a huge amount of data that can be used for research and to improve learning outcomes. Some examples include:

- cumulative and individual students' attendance throughout the semester;
- recurring incorrect answers that may indicate a misconception;
- testing the commonly held belief that students in the front row perform better than the ones in the back;
- Studying the impact of grouping on the change in answer on individual students or as the semester progresses.

It can also be used to survey students during the semester to ask for their feedback on the class and pedagogy. A survey of 105 students enrolled in the course in fall 2018, administered at the beginning of week 4, showed that 60% found in-class discussions and short lectures most helpful, followed by Learning Catalytics (53%), online homework (49%), working with their peers (37%), and reading the textbook (22%).

Conclusions

SRSs provide a convenient and versatile way for instructors to engage students through formative and summative assessment, and to record student responses and use them to improve learning outcomes. Based on four years of experience with Learning Catalytics™, this SRS designed to support the peer instruction and Just-in-Time Teaching pedagogies provides all the features of the more advanced SRSs with the ability to automatically pair up students and facilitate peer-to-peer learning. However, it is unclear if using technology to implement peer instruction is better than simply using flashcards (Lasry, 2008). But no matter what we use to engage students, the key is their learning and engagement, and peer instruction delivers that.

Acknowledgments

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