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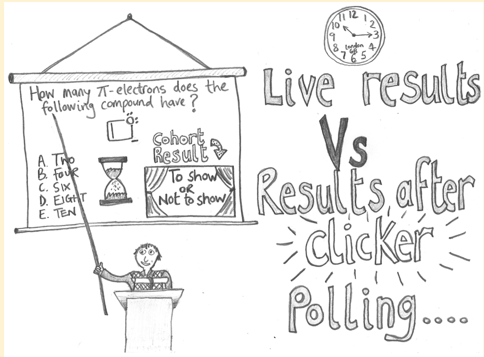
Exploring Peer Instruction: Should Cohort Clicker Responses Appear During or After Polling?

Russell J. Pearson*

School of Pharmacy, Keele University, Hornbeam Building, Keele, Staffordshire ST5 5BG, United Kingdom

ABSTRACT: During problem-based learning sessions, undergraduate students were tasked with answering chemistry-related questions using clicker-handset technology in which the last response made by each handset would override any previous vote. The benefits, if any, of showing cohort responses from clicker questions during versus after polling were explored. Preliminary work suggested that cohort responses shown live during polling created greater unprompted peer instruction, which was inferred from a noticeably louder level of classroom debate. To test if subtle polling changes can promote greater peer instruction, this study monitored cohort performance, clicker response times, and voting-behavior patterns throughout the polling process. Profiling individual and team-based clicker activity in this manner highlighted contrasting performance data. No significant differences were seen when clicker handsets were used individually by students; however, certain trends were seen in the team-based model, which depended on how cohort responses were displayed and were also influenced by question type, with multiple-choice questions (MCQs) performing differently from true−false style questions. The results highlight improved performance in the team-based clicker model with peer instruction taking place during MCQ polls in which cohort responses were displayed live during voting. These findings highlight a clicker strategy embedded with peer instruction that bypasses the need for the standard three-phase process of polling, discussing, and then repolling. Displaying polling responses live enables multiple polling and discussion opportunities to occur in a single interchangeable phase, thus providing a time-efficient voting and peer-instruction method that may attract more instructors to adopt clicker technology within their teaching.



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Peer instruction has been shown to improve problem-solving skills and produce learning gains, with students actively engaged and often better positioned to address each other's confusion and misconceptions than the instructor when faced with conceptual questions.[1−6] When used alongside clicker technology, much of the success associated with peer instruction is reliant on both question design[7,8] and the instructional approach.[9] Irrespective of the class size, the technology can only be justified and promoted if it assists the pedagogy. This has become a commonly shared view when considering clicker technology.[10] The role of clickers as a viable teaching tool has been well documented, with evidence that an active-learning environment can be created, even for large cohorts, where students learn and retain concepts better with instant feedback on offer to both the student and instructor.[6]

On the topic of instructional approach, this work explores how best to display clicker votes in a chemistry setting to encourage greater peer instruction and to make the uptake of classroom response systems among chemistry instructors a more attractive option, because overall usage has been reported to be relatively low.[11] The author's previous work on the use of clicker technology in problem-based learning sessions found that a team-based clicker model involving three to five students per team led to better student exam performance and improved student retention while also generating more favorable student survey data when compared against individual clicker-handset usage.[12] As a result, a team-based clicker model involving teams of three to five students with one handset per team was also used in this work, with comparisons again being made to an individual clicker approach in which all students had their own individual handset.

It is noteworthy at this point to draw a distinction between the peer instruction proposed in this work and peer-led team learning (PLTL), also known as Workshop Chemistry, which has been widely reported elsewhere.[13−17] PLTL usually involves larger teams of 6−10 students and a trained peer leader or facilitator with good leadership and interpersonal skills that has already successfully completed the course. Although the latter approach has proved to be beneficial at bringing incoming students to a similar level of self-management and scientific reasoning, less success was made in some cases at equalizing their basic knowledge.[18] In

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contrast, the team-based work described herein is different in terms of team size and composition, and the peer discussion of cohort responses also differs in that cohort responses are displayed live (i.e., in parallel) with student discussions and the polling process.

As a new form of clicker-integrated instruction different to that reported elsewhere,[19,20] this work assessed the added value, if any, of showing cohort voting responses live while the clicker poll remained open. Brooks reported the closest prior study to that described here, in which junior-level undergraduate students were studying a module on chemical thermodynamics.[21] Each student voted individually with a clicker and then wrote reflective explanations, as adopted elsewhere.[22] The students then reported their confidence on a Likert scale and discussed their choices in small, self-selected groups, and initial cohort responses, which were described as "intermediate results" were either shown or omitted prior to the group discussion. This was then followed by a repoll with the aim of encouraging students to learn from and teach others. The latter aim clearly remains the goal of this work, but the key difference here is the evaluation of both an individual model and a team-based model alongside clicker responses that are either hidden or shown in real-time while students continue to vote, discuss, and potentially revote.

Previous work has shown students' preference for the use of traditional clickers over web-enabled mobile devices.[12] Results highlighted that 90% (N = 79) preferred the use of dedicated clicker handsets, citing logistical issues with mobile-phone technology, such as poor web connectivity, mobile-phone incompatibility, and low battery levels, which have been reported by others;[23] however, the most significant student concern related to the inappropriate use of mobile technology and the potential distractions that it can cause in a large classroom setting. These observations have been reinforced by many others,[23−29] although it is also acknowledged that web-based classroom response systems have been reported to increase collaborative learning and class engagement for some users who instead favor the use of mobile-phone devices as an inexpensive, popular polling tool.[30−33] Throughout this study, traditional radio-frequency clicker handsets were the voting tool of choice to ensure all student discussion and debate remained firmly in the classroom and off-line, allowing students to fully appreciate and rectify any of their knowledge gaps or misconceptions in a distraction-free environment.

■ METHODOLOGY

Studying this novel clicker approach in both a team-based and individual-student model was possible using Turning Technologies NXT and RF LCD handsets, respectively. Individual clicker handsets were distributed annually in student welcome packs on a year-long loan. In the team-based model, the handsets were provided on entry to lecture theaters using a clear numbering system unique to each clicker team; the latter was logistically possible since far fewer handsets were needed for the team-based model.

Evaluation of in-class clicker performance was achievable following scrutiny of sessional reports, all of which were automatically generated by the Turning Technologies software. In all problem-based learning sessions, questions were presented as an assortment in which cohort responses were shown either during (live) or after polling. Because of the range of true−false and multiple-choice style questions (MCQs) used, attempts were made to pair-up questions of varying difficulty (on the basis of historical question performance over a number of teaching cycles) to ensure that any variations in data were a consequence of the format used for displaying the polled result (live responses versus responses only available after the poll had closed). The instructor did not provide any guidance relating to the content of the clicker question during polling; however, cohort responses were discussed alongside the correct answer after closing each clicker poll, with the instructor also giving full explanations and fielding questions from the class where necessary.

In addition to using sessional reports, screen-shot video capture of each teaching session was thoroughly reviewed at 10 s intervals using Snagit software to allow response times and other observations relating to student voting behavior to be scrutinized. All questions were based on chemistry content delivered to classes containing both undergraduate pharmacy and pharmaceutical science students in their first and second years of study. On the basis of strict university-entry grade requirements and a structured interview process, all recruited students demonstrated a similar overall standard, generating cohort sizes that ranged from 96 to 146 students. Cohort clicker data were collected on the individual clicker model from first-year undergraduates across two consecutive years (N = 118 and 146), whereas the participants for the team-based model were second year undergraduates, again across two consecutive academic years (N = 96 and 127). No ethical approval was required in this study because all collected cohort data and student feedback were treated anonymously, and video recordings only involved screen-capture footage rather than any student participants.

Problem-based learning linked with the clicker platform was embedded into lectures, workshops, and problem classes using true−false questions and MCQs that were all single best answer with the number of response options varying between three and eight choices. All such sessions, which were either 50 or 100 min in length, were delivered to full cohorts (100%) or in 50 or 33% groupings. The number of clicker questions used per session ranged between 4 and 16 and was dependent on the session type, with problem classes and lecture sessions being the most and least question rich, respectively. In the individual clicker model, all results were collected anonymously, whereas in the self-selected-team-based model, each handset was linked to a specific team identifier and each question carried a points value of 10 to allow a team leaderboard to be constructed and updated over the course of a semester-long teaching period. Team points were not awarded on the basis of the speed of voting; instead all point scoring was based on the final vote lodged by each team's clicker handset for a given question. Upon completion of the team-based clicker competition, all team data were anonymized because this was a formative exercise and none of the collected points were credit-bearing toward course grades.

Throughout all of the work involving the individual and team-based clicker models, the last response recorded on each clicker handset for a given question was able to override any previous vote linked to that particular poll. Student evaluations of their clicker sessions were done anonymously using clicker handsets and also through course-evaluation questionnaires. In the case of the clicker platform, for the team-based model, the number of recordable responses increased on such survey polls to five to match the maximum number of participants in each team (three to five students), thus ensuring that all students were able to provide their own personal feedback on the one

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handset regardless of the views of others within their clicker team.

■ COHORT PERFORMANCE

Using an individual clicker model, where each student had a Turning Technologies RF LCD clicker handset, no improvements to in-class clicker performance were noted when cohort responses were displayed live rather than after polling had closed. This investigation was applied to material on chirality and functional-group chemistry and involved comparing the two formats for displaying clicker responses within the same cohort (*N* = 146) and also across two different cohorts (*N* = 118 and 146). Between cohorts and for separate groups within the same cohort, half of the questions had responses shown live, and the other half were only displayed after polling was complete.

It was clearly evident from the data generated for the individual clicker model that the overall average percentage of correct answers was unaffected by the manner in which the cohort responses were presented. Across 16 different MCQs on functional-group chemistry, scores of 61.5 versus 60.3% were seen between different cohorts (*N* = 118 and 146) for responses displayed during and after polling, respectively, whereas 33.1 versus 33.7% was seen on the topic of chirality for two equally sized groups within the same cohort (*N* = 146) for responses again displayed during and after polling, respectively. These results are consistent with findings by Brooks who also saw no clear differences in clicker scores between cohorts who did and did not see intermediate results in their peer-instruction model.[21] However, as already described, their model relied on small-group discussions and a separate repolling event, both of which were absent with this individual clicker model, although students were still encouraged to interact with each other but in a less formal manner.

In sharp contrast, the mean cohort score when using Turning Technologies NXT handsets in a team-based clicker model (with three to five students per team, as recommended by others)[34,35] was 67.4 versus 58.4% (*N* = 96) for live responses versus responses only after polling. These data were collected across 31 MCQs and related to subject matter on NMR spectroscopy and aromatic chemistry. Each question in this study was awarded a credit value of 10 to allow a team leaderboard to be constructed. Interestingly, across 17 different questions, in-class performance within this same cohort showed the opposite pattern when applying exactly the same model to true−false questions; 68.5% correct versus 83.7% correct (*N* = 96) for live responses versus responses only after polling.

To avoid the misinterpretation of clicker data and to test if these variations were simply due to subtle differences in question difficulty between the two question sets rather than the influence of displaying live responses versus responses only after polling closes, the team-based clicker study was extended by a further year. A new cohort (*N* = 127) received the same 48 questions (31 MCQs and 17 true−false questions), but the format for each question was flipped, so those questions that were previously used with live responses became questions where the cohort response was only displayed after polling and vice versa. For the MCQs, cohort performance for live responses versus responses after polling was 63.8 versus 57.0% (*N* = 127), which followed the same trend from the previous year (*N* = 96), whereas for true−false questions, the cohort performance for live responses versus responses after polling was 84.1 versus 78.6% (*N* = 127), showing a reversal of the previous trend (*N* = 96).

The team-based results indicate that MCQ polls with live responses enhance performance and discussion, because of both intrateam peer instruction (peer instruction from within the clicker team) and interteam peer instruction (peer instruction based on the responses lodged by other teams), but for true−false questions the same does not apply. These findings could be attributed to the class being easily polarized in the wrong direction, especially with questions designed to address common misconceptions among students, which would be further exaggerated by the higher percentages that are inevitable with true−false questions because of them only having two possible response options. On the basis of these results, MCQs should be treated differently from true−false questions when integrated with clicker technology. These observations are reinforced by Perez, who reported how biology students viewing intermediate polling responses are more easily biased and often adopt the common answer when attempting true−false questions compared with when they attempt MCQs.[36]

Figure 1 represents one example of a favorably attempted single-best-answer MCQ with five answer choices in which the cohort responses from the team-based clicker model were displayed live during the polling process. In this example, the poll was deliberately left open for an extended period to allow student-voting behavior to be fully explored (*N* = 96). It should be noted that the last response from each team was able to override any previous vote by that team. In this particular case, an incorrect answer was initially the most popular response, with the correct answer only dominating after all 25 teams had voted at least once.

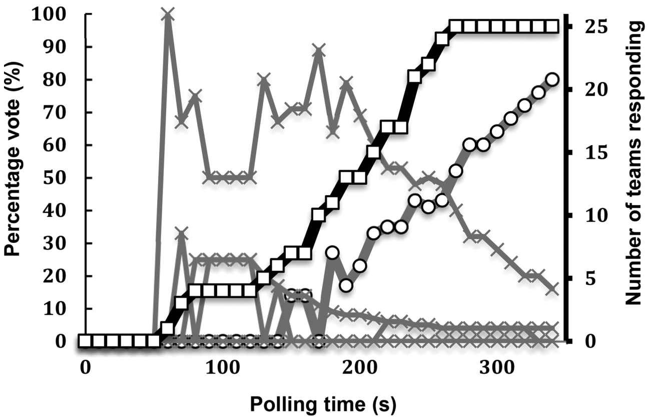

Figure 1. Comparison of how the votes for a five-answer MCQ on NMR spectroscopy changed with live polling and an extended voting time across 25 teams using NXT handsets (*N* = 96). All time-point data were collected using Snagit screen-shot-capture software. Gray crosses with gray lines represent four different incorrect responses, open circles with a thick gray line represent the correct response, and open squares with a thick black line represent the number of teams lodging their initial response (in line with the second vertical axis). Note that the last response from each team overrides any previous vote by that particular team while the vote remains open. In this question, students were required to match the correct chemical structure from a choice of five (A−E) to a broad-band decoupled ^{13}C NMR spectrum that was provided as a printed handout.

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The plot shown above supports the notion that the ratio of correct to incorrect responses increases significantly when voting time is extended; in the case of the data presented in Figure 1, a rise in correct responses from 52 to 80% is seen in a 70 s period following the time point when all teams had initially voted at least once. It is fascinating to note that the 28% switch in answer choice is identical to that described by Perez for repolled MCQs after students had initially seen an intermediate vote highlighting the most common response.[36] Perez questions whether this observation is down to students simply being biased on their second vote because of the presentation of the intermediate responses. This is a noteworthy explanation, but the same reasoning cannot be used for profiles such as that displayed in Figure 1, where the most common initial response eventually received only 16% of the entire vote, finishing 64% behind the most popular choice, which was also the correct answer.

■ CLICKER RESPONSE TIMES

Conscious that any fluctuations in clicker performance may simply be attributable to the length of polling time alone, the average polling times for all types of questions included in the team-based clicker study were compared. As described previously, for each question shown with live response polling, a question of similar difficulty was included for which the polling responses were only shown after polling had closed. Figure 2 demonstrates remarkable similarities between the average polling times when comparing questions with live responses and those for which responses were only displayed after polling closed (N = 96).

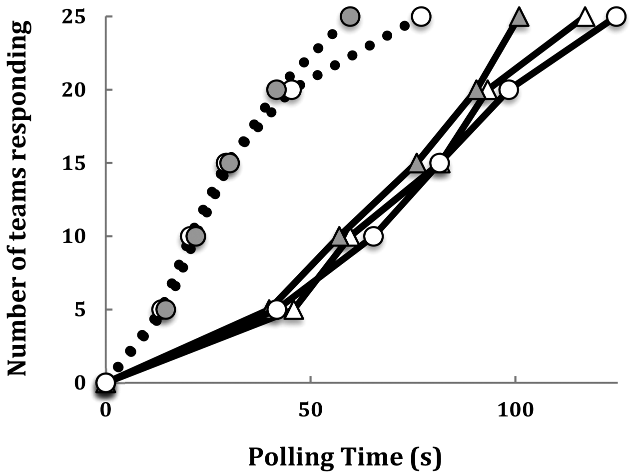

Figure 2. Comparison of average response times for teams to lodge their initial votes across 44 questions when cohort responses were shown live (during) or after polling to a class of 96 students (25 teams using NXT handsets). The five profiles represent 9 examples of true–false questions on aromatic chemistry with responses shown after polling (gray circles with a dotted line), 8 examples of true–false questions on aromatic chemistry with responses shown live (white circles with a dotted line), 10 examples of MCQs (three or more response options) on NMR with responses shown after polling (gray triangles with a solid line), 9 examples of MCQs (three or more response options) on NMR with responses shown live (white triangles with a solid line), and 8 examples of MCQs (three or more response options) on aromatic chemistry with responses shown live (white circles with a solid line).

As expected, the average polling times were longer for MCQs (with three to eight response options) than for true–false questions because the MCQs had more options to contemplate. Clearly, students have more to read and consider with questions that contain more response options. In Figure 2, it is reassuring to see from the three MCQ profiles (represented by solid lines) that the average polling times required for all teams to lodge their initial vote fall within the range of 101–125 s, which is consistent with work by Turpen who reported average polling times between 100 and 153 s following semester-long observations of clicker sessions involving six physics instructors.[37] Unlike in Figure 1, which showed an extended voting time, in all other cases once every team had provided a vote the poll was closed.

Figure 2 also illustrates consistency in the average polling times when the problem subject matter switched, in this case between aromatic chemistry (circles) and NMR spectroscopy (triangles). This is evident through comparison of the profiles for the MCQs on the two topics (white circles with a solid line and white triangles with a solid line, respectively). The standout result with both the true–false questions (dotted lines) and MCQs (solid lines) was that the slowest 20% of responding teams responded even slower (an average of 17 s slower) when provided with the live polling responses (cf. profiles with gray markers vs those with white markers). This may suggest that the live-response format fosters greater uncertainty within slower, less confident teams because of additional peer-instruction influences that are external to the team itself (interteam peer instruction).

■ FURTHER DISCUSSION AND OBSERVATIONS

Profiling team-based clicker behavior using live polling responses showed benefits to in-class student performance when answering MCQs. For true–false questions, voting in most cases was highly polarized in favor of one option. The improved cohort performance in the team model for MCQs can be explained by peer instruction within the team (intrateam peer instruction) alongside peer instruction between teams (interteam peer instruction). This instinctively occurred when displaying cohort responses live during such clicker polls.

Although live cohort responses can provide misleading MCQ answers after approximately 10 teams have responded, far more reliable answers were displayed after 25 teams had voted (see Figure 1). Interestingly, during live response polls, students did not know how many team responses were contributing to the percentages displayed on the PowerPoint slide, which helps explain why some teams were, on occasion, misled by interteam peer instruction. It was also observed with live response polls that leaving a lag time after all teams had initially responded led to many teams changing their answers. This proved to be beneficial for the majority of teams.

Differences in team performance cannot be explained by the length of polling time alone, because 80% of the class gave their initial responses at virtually the same rate regardless of whether live polling was in operation or not (see Figure 2). As reported by Lasry, the last 20% of all clicker responders tend to be the least confident voters,[38] which would explain the pattern of slower voting that was evident in this work for the last 5 responding teams (of the 25 teams represented in Figure 2) when answering both the true–false questions and MCQs with the additional distraction of live polling responses.

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Despite live polling responses creating notable variations in voting behavior and performance for the team-based clicker model, when the team approach was replaced with the individual clicker handset model, no such patterns were observed. In the case of the latter model, the type of subject matter used to construct the MCQs was changed from the topic of functional-group chemistry to chirality, and the behavior within and between two different cohorts (N = 118 and 146), of a comparable standard, was also studied, but still no differences were observed. This may point to previous findings, which concluded that individual clicker usage does not foster significant peer instruction. This was observed even when questions were repolled in cases where the class had seen a split poll from the first round of voting.[12]

Improvements to in-class student performance in the team-based clicker model with live response polling supports the existence of intrateam peer instruction alongside peer instruction using the response data available from other teams (interteam peer instruction). However, it is fascinating to see that this notion is not supported by student feedback in the team-based model which showed an overwhelming preference for cohort results to be displayed after polling (84%, N = 86, and 71%, N = 106), with only 3−4% preferring live polling and 13−25% opting for a mixture of both.

These results may be rationalized on the basis of the competitive nature that was adopted among the teams during these problem-based learning sessions, which may have been heightened by the inclusion of league tables and prizes for the best performing teams. However, this explanation is somewhat questionable as students using the individual clicker model, without a league table, gave similar feedback, with 75% (N = 73) and 84% (N = 93) preferring clicker responses to only be displayed after polling. It is noteworthy here to share comments voiced by students who believe that clicker sessions of the type described foster a friendly mock-exam-style setting, which enables recognition of what is and is not known. Perhaps the live response polls are therefore viewed by some students as being rather destructive to the mock-exam-like environment, albeit a somewhat more relaxed and fun one than an actual exam setting, that clicker sessions generate.

From anonymous student feedback following completion of the team-based clicker work, the vast majority commented very favorably on the clicker sessions through teaching-evaluation questionnaires and through the clicker platform using comment options, with 86% (N = 84) and 83% (N = 95) either agreeing or strongly agreeing that they would welcome more regular clicker usage in their course and 94% (N = 81) and 90% (N = 90) also wishing to see clicker technology remain a feature within their peer-instruction sessions. In addition, 94% (N = 28) and 90% (N = 98) of students gave the clicker peer-instruction sessions overall scores of 7−10 out of 10. Interestingly, a study by Niemeyer has highlighted gender differences when questioning chemistry students on how clickers affect their class experience, with females responding more favorably.[39] No gender-specific analysis was performed here, but it is interesting to note that within the pharmacy cohorts that account for the majority of students surveyed in this work, the female to male ratio is consistently in the region of 7:3; thus, a greater female presence may, in part, explain the highly favorable feedback received.

A further tactic employed during this study was the inclusion of occasional MCQs with more than one correct response option without this being explained in the question stem. As an example, across two separate cohorts in the team-based model for an MCQ on NMR with five response options, live polling responses led to 80% and 0% (N = 25 teams) voting for each of the correct answers, versus 52% and 38% (N = 29 teams) for each correct answer when the voting was revealed only once the poll had closed. Similarly, for a five response option MCQ on aromatic chemistry with two correct responses, live polling responses led to 80% and 13% (N = 30 teams) for each correct answer, versus 50% and 35% (N = 26 teams) for each correct answer when results were shown after polling. Although the overall percentages of teams obtaining the correct answers were quite similar in both of these cases, it does demonstrate that the live polling may in certain cases polarize the vote and distract less confident students away from their gut-instinct, as was also observed with the true−false questions. However, this could also be viewed as a positive learning experience whereby an element of doubt is introduced that stimulates a deeper level of in-class debate and peer instruction.

Across the two-year study, each MCQ in the team-based model was tested with live responses and also with responses only visible once the polling had closed. It was therefore possible to establish for each MCQ the format under which it performed best. Out of 31 MCQs tested on two separate cohorts, resulting in a total of 56 teams (223 students), higher cohort scores were achieved in a ratio of 21:10 in favor of showing live responses during each poll. Despite over twice as many questions performing better with live response polls, the improvements in overall in-class cohort-performance scores were only seen to be between 6.8 and 9.0% across the two large cohorts studied (N = 96 and 127) for MCQs polled with live responses on display. This can be explained, in part, by comparing the best and worst cohort-performance scores across the 31 MCQs for live response polls with the same extremes where responses were displayed after polling. In the case of the latter, the percentage of correct responses across all 31 questions ranged between 9 and 97%, whereas for the live response polls, the same range was between 0 and 100%, with these latter extremes being quite commonly seen in live response polling because of students being strongly influenced in one direction or the other.

In summary, the classes using the team-based clicker model performed better on MCQs during live response polls; however, on occasions when students did get things wrong, this would sporadically lead to everyone or at least the vast majority being incorrect. This clearly had a significant effect on the overall in-class cohort-performance figures and confirmed that some student voting was likely to have been biased by a common answer being on display. More importantly perhaps, results of this kind noticeably shocked many students, which has been reported elsewhere as the eye-opening moment during such sessions,[6] hopefully encouraging students to further debate and reflect.

■ CONCLUSION

In short, the subtleties embedded within question design and the chosen clicker approach can significantly influence student-voting behavior. Presenting the class with live clicker polling responses during voting can lead to greater peer instruction and improved overall cohort performance when applied to the team-based clicker model for MCQs with three or more response options. Displaying live polling responses had no beneficial effect for true−false style questions in the team-based model and no noticeable effect at all on MCQ-style

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questions when students voted individually with their own clicker handsets.

Instructors who display live response polls while clicker teams continue to vote and engage in peer instruction are rewarded by significant time efficiency that suits fast-moving, problem-based learning sessions. This is clearly advantageous over alternative approaches that require two different polling events on either side of a peer-discussion phase. Finally, when displaying clicker responses live (during polling), instructors should be mindful that discussions will continue even after all clicker teams have lodged their initial response. Screen-shot footage during live response polls confirms that many clicker teams will change their mind, which reinforces the idea of intra- and interteam peer instruction taking place before, during, and after each selected vote.

AUTHOR INFORMATION

Corresponding Author

*E-mail: r.j.pearson@keele.ac.uk.

ORCID

Russell J. Pearson: 0000-0003-1705-5609

Notes

The author declares no competing financial interest.

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