Effectiveness of An Innovative Application of Learning Technology in College Genetics

Lipika Neshmin Arif David S. Williams S. Raj Chaudhury
University of South Alabama

Abstract

Teaching and learning approaches in the college classroom can be enhanced beyond the traditional lecture by using technological tools and research-based instructional techniques. In particular, instructional technology can allow large numbers of students to engage with content, instructors, and each other in a meaningful learning process. Clickers, an example of such instructional technology, are personal response systems used to create an interactive learning environment in university lecture classes. Several research studies have shown that clickers, paired with the appropriate pedagogy, have a desirable impact on student outcomes in terms of higher attendance, increased engagement, and improved exam scores, which leads to overall enhanced learning outcomes. In this study, we specifically examined student performance on the final exam after using a peer instruction strategy with clickers in an post-exam review on earlier exams. The class was a large (approximately 130 students) introductory genetics course at a regional, public research university in the southeastern United States. The results showed significant improvement in student performance from the initial exam to the final exam on difficult concepts addressed using clicker-aided peer instruction.

Keywords: Peer-assisted learning, Metacognitive Skills, Active Student Engagement

Introduction

There is sustained interest within research on teaching and learning to determine effective instructional strategies for improving student engagement, understanding, and success (Kahu & Nelson, 2018). Active learning and other learner-centered pedagogies have been developed to address the challenges in higher education in terms of learning, engagement, retention, and progression (Freeman et al., 2014). In the past two decades, learning technologies have emerged as significant aspects in the design and delivery of instruction in most educational settings. However, ubiquitous access to technology is not a learning panacea. Bruff (2019) argues that "teaching and learning goals should drive instructors' technology use, not the other way around." When technology is matched with pedagogy, instructors can increase student engagement in a meaningful learning process.

As an active learning tool, the clicker is a popular technology that is effective in large classrooms. Specifically, it is an effective tool for engaging students in responding to an instructor-posed question and providing real-time feedback on students' conceptual understanding of the topic (Bruff 2009; Chien et al., 2016). Over the past two decades, an increasing body of literature shows how clickers support an active learning approach in higher education (Bruff, 2009; Mayer et al., 2009; Shapiro et al., 2017). Clickers are known by various names such as Student Response Systems, Classroom Response Systems, Personal Response Systems, and Audience Response Technology (Roush & Song, 2013). They all have similar functionality that gives learners real-time feedback on questions posed by the instructor. In addition, dedicated hardware is now used in conjunction with clicker systems using mobile-based apps that allow students to engage with clicker activities through WiFi or mobile data.

Although many effective interactive teaching methods are used in large classes, peer-assisted learning (formally "peer instruction") is a well-established method widely used in educational settings (Mazur, 1997; Topping, 2005). Mazur and Somers (1999) found that peer instruction expedites students' learning by providing opportunities for students to explain their reasoning to one another. There are a few studies (Elind et al., 2012; Lucus, 2009) that focus on facilitating peer instruction using clickers in a classroom. However, a recent literature review by Vickrey et. al. (2015) which summarizes various studies on research-based models from effective implementation of peer instruction does not appear to address the particular clicker use strategy presentd in this paper. Therefore, we aim to fill this gap in the literature by measuring the effectiveness of a novel application of peer-assisted learning using clickers in a large enrollment biology course.

The specific method for the peer instruction described in this paper was developed from a presentation by Weiss (2017). She described using a required student consensus of the correct solution to questions as a means to promote peer-assisted learning for tackling difficult concepts that students missed on a test. As described by Weiss, after a test, a portion of time at the beginning of the next class was used for students to rework missed test problems that dealt with important concepts. Students came to a consensus for the problems that they were reworking. Then, the instructor would display a question to the class, and the students had a prescribed amount of time to come up with a solution. During these times, students could move around the room and interact with each other to work on the problem as the class consisted of 25 to 40 students. At the end of the allotted time, the students were required to hand in one solution to the problem that contained each student's signature. If the solution was correct, all students signing the solution were given points toward the test.

This method was applied in an introductory Biology class with 130 students. As a large class, it was challenging for the instructor to make students reach a consensus or discuss with one another as a whole class. Additionally, it would be extremely difficult for 130 students to read through the final solution and sign the paperwork for credit. It would also be time-consuming for an instructor to identify the appropriate signatures to give each of the students credit. To avoid these problems, the instructor decided to use clickers to facilitate students' ability to convey their answers to each other in the large auditorium class. After displaying a question on the large screen, the instructor encouraged students to work through the problem with their neighbors as a pair and then select their answers via clicker. The instructor displayed student answer choices on the projection screen so that the entire class could see. Although student responses are anonymous on the projection screen, student identity data is available for the instructor in the clicker system for assessment. The estimated given percentage of answers recorded in the clicker system legitimate students' consensus within their pair. The technology helped the instructor easily assign credit to those students who provided the correct answer.

Peer instruction in a pair or small groups was the pathway for students to reach consensus. The instructor encouraged discussion but did not actively participate in clarifying student misconceptions while they were voting. We aim to examine how this particular approach of using clickers affects student performance on the final exam. Based on innovative clicker practices, peer instruction on difficult concepts, the current study specifically assesses the change in students' performance from initial exams (before clicker-enabled review in the classroom) to the final exam (after review).

This study will make a significant contribution to the existing literature on active learning strategy by bringing the specific perspective of using clickers for peer-assisted exam-review focused on difficult concept learning in a large lecture class. Applying this technique will help the instructor transform the traditional lecture format into an inclusive environment by facilitating student engagement in reflection, discussion, participation, and assessment. The implication of this study will be noteworthy for bringing individual critical thinking through a collaborative learning environment. Furthermore, this study will contribute to the literature on the pedagogy of critical thinking and the use of clicker technology for classroom learning.

Literature Review

Clickers in Active Teaching and Learning

Instructional technologies, often developed by faculty innovators, have had an immense impact on designing and delivering instruction in college and university settings. For example, instructors frequently use clickers to implement an active learning strategy to increase student engagement and meet learning outcomes. Using clickers in the classroom has positive effects on various student outcomes. Bruff (2009) provides an overview of the historical development of clickers as applied to a wide variety of teaching areas, such as assessing students' understanding related to the topic, regular and frequent feedback, and increased participation for successful learning.

Using clickers consistently rather than intermittently in a class has positive outcomes in improving instructor-student communication and student-student interactions (Nagy-Shadman & Desrochers, 2008). Hubbard and Couch (2018) stated that clickers improve performance, attendance, exam scores, student engagement through active participation in class discussions, self-efficacy, and perceived academic control. Hodges et al. (2017) found that clickers can promote learning complex skills by cultivating motivation for the task, building on prior knowledge and skills, receiving immediate feedback, and repeating the learning task. Patterson et al. (2010) suggested that clickers bring a positive addition to the classroom by anonymizing student responses, validating the answer through immediate feedback, and providing a collaborative and engaging classroom environment.

Reinforcing Learning Through Peer-Assisted Instruction

In a traditional classroom setting, instructors ask questions to gauge students' understanding, assess their prior knowledge, stimulate their attention, and promote their thinking (Alsup, 2004). Often only highly motivated or outgoing students voluntarily answer questions. Peer-assisted instruction is a method in which students are allowed to work together in pairs and small groups to discuss and defend their responses (Mazur, 1997). In Mazur's formulation, peer-assisted learning or peer instruction (PI) aims to actively engage all students during lectures through a structured questioning process. An instructor presents clicker questions to the students based on the lecture in a clicker classroom. Specific time is allowed for students to think and respond to the question individually, and then students are allowed to discuss the concepts with their peers regarding the question. Students are then asked to answer a similar/same question again based on their discussion and may change their answer choice. This process engages all students to participate in the discussion, ask questions, and apply core concepts. Therefore, students are reinforced to learn as they conceptualize and comprehend the core concepts through discussion with their peers.

The peer learning aspect of using clickers in the classroom was shown to be especially effective when students answer a question incorrectly (Smith et al., 2011). Kulesza et al. (2014) also reported that clicker quizzes provide the potential for continuous formative assessment as both students and professors can be informed about students' learning progress with the presence of timely feedback.

Metacognition

The appropriate use of clickers in the classroom can enhance students' metacognition. Metacognition is defined as the act of thinking about one's cognitive process (Korhasan, Eryilmaz, & Erkoc, 2019). Levy et al. (2017) argued that using clickers in the classroom improves students' understanding of complex topics and increases their levels of understanding. Including clickers as part of one's class potentially advances student learning experiences and understanding of related course materials in core requirement classes (Premuroso et al., 2011). Students can judge their knowledge and understanding through engaging themselves in a metacognitive process that cannot easily be achieved during regular instruction (Nagel & Lindsey, 2018).

Molborn and Hoekstra (2010) found that passive students who are afforded anonymity are also motivated to engage them in commenting and explaining their responses when the histogram is displayed after student responses. When students are allowed to review the clicker question, it encourages them to engage in reflection on their level of comprehension. Through this process, students interact with their knowledge on the topic. The use of clicker questions that review students' understanding requires them to develop critical thinking and increase comprehension of the core concepts (Mollborn & Hoekstra, 2010). When the instructor provides thought-provoking questions, learners are encouraged to actively engage in appropriate cognitive processes and promote critical thinking skills. In addition, student learning gains were the greatest when students were asked difficult rather than easy questions (Smith, 2009). McDonough and Foote (2015) found that the clicker use strategy encourages students to analyze question difficulty when they work cooperatively.

Mayer et al. (2009) conducted a study to test student performance using no-clicker (control) and clicker groups. The clicker group scored higher in midterm and final exams than the no-clicker group. In addition, they noted that some components of active learning, including paying attention to the lecture, organizing and integrating learned knowledge for answering questions, and developing metacognitive skills for assessing student understanding of the contents, might contribute to their performance in exams. Moreover, other studies have shown that while many students prefer the anonymity of clickers, it still works for assessing their level of understanding against their peers (Caldwell, 2007). Therefore, using a clicker strategy may encourage metacognition.

Active Student Engagement

There is an abundance of research related to clickers in the classroom that focus on student engagement and interaction. Active engagement, an effect of active learning, is considered an important outcome of using clickers in the classroom. Graham (2013) stated that using clickers regularly may transform a classroom positively by engaging students in learning who would not usually be willing to participate in classroom discussions. Therefore, the use of clickers in the classroom can increase the participation of reluctant students in in-class activities. Wong (2016) mentioned that clickers help students reduce their language and communication barriers and increase their involvement in the course rather than be just passive listeners and note-takers.

The possibility of increased interaction and participation encourages students to take responsibility for their learning. Patterson et al. (2010) suggested that clickers bring a positive addition to the classroom through the anonymity of students' responses, validating the answer through immediate feedback, and providing a collaborative and engaging classroom environment. Thus, as an active learning strategy, applying clickers in the classroom enhances student learning in multiple ways. For example, clicker use creates an atmosphere in a classroom where students' interaction with content and active engagement improves their critical thinking and ability to apply course knowledge. In addition, Addison et al. (2009) found that students have positive perceptions of the effects of the clickers in terms of their attention, engagement, and participation in the class.

Method

Procedure for reinforced peer learning through clickers for questions on which students performed poorly on tests.

The current study builds on peer-assisted learning by incorporating consensus building into the design and delivery of clicker questions. We hypothesize that these strategies should significantly improve student performance when similar concepts are tested on the final exam compared to exams earlier in the semester. Students in the introductory genetics course were assessed on three tests and a cumulative final exam. Most of the students were second or third-year students at the university. Only students who completed all three initial tests and the final exam were selected for this study.

After students completed each initial test, questions that more than 50% of the class got incorrect were flagged by the instructor. In Fall 2018, a subset of the flagged questions, approximately nine questions from all three tests, were selected for bonus point considerations because the concepts that these questions covered were essential to the overall learning outcomes of the class. Test questions that were more tangential to the main concepts of the class were excluded from being selected. After each of the tests, the selected questions were presented to the students for them to rework as a small group so as to reinforce the material and attain bonus points toward their grades on the test.

The first 10-15 minutes of two class periods following the test were dedicated to the students reworking the questions. Before working on the questions, students were informed that they must come to a consensus as a small group about the correct answer to earn full bonus credit on that question. For example, if only 90% of the students came to the correct answer, those students who answered correctly would only receive 90% of the total bonus points added to their exam scores. This rule was implemented to give students an incentive to reach a consensus about the ideas and enhance peer dialogue. Students were also informed that it was imperative to use this time to learn the concepts from these questions because a subset of the concepts of the questions would be asked in a different format on the final exam.

In order to efficiently gather responses from all students in the large class of 130 students, clickers were used. Each question was projected using PowerPoint exactly how it was written in the test with the corresponding multiple-choice answers. Students were encouraged to work through the problem with their neighbors and select their answers via clicker. The instructor would wait until she saw on the clicker base display (visible only to her) that approximately half of the class had recorded an answer by a clicker. Then the instructor would ask the whole class to alert her when they wanted the histogram of the class answers to be displayed in the class though voting would not be ended. After students requested a public showing of the class distribution of responses, the instructor would then show the histogram to the class. Showing the histogram often led to a quick increase in the number of votes for the answer that already had the highest number of votes. Once the highest number of students grasped the same answer, approximately 80-90% of students, the instructor observed that students would engage in a peer discussion to justify that the most popular answer was also the correct answer. The motivation to achieve as close to full consensus as possible (in order to maximize the number of bonus points students could receive) fueled the observed peer discussion. The instructor would not participate in the class discussion or answer questions during this process. In all but one of these clickers-mediated bonus questions students not only achieved consensus but also selected the correct answer choice, thus attaining the maximum bonus points toward their test. In the one case where students did not reach a complete consensus, they asked for the polling to be finalized and moved on. It is noteworthy that even in this case, most students did arrive at the correct answer.

After both review sessions were completed for a test, the instructor would then post the slides of the bonus review on the course learning management system (LMS) site. If students were not present for the bonus review questions, they were able to write a paragraph explaining the reasoning of the correct answer accurately; the student would be rewarded with bonus points for their test. Thus all students in the course had an opportunity to revisit concepts covered in the bonus review, whether or not they participated in the formal clicker review.

The concepts addressed by the clicker review process were selected by the instructor's determination that they were important learning outcomes for the course. Approximately a third of the concepts from the clicker review questions were used as questions on the final, consistent with a focus on the importance of these concepts. The review method was a way to indicate to the students some of the concepts that the instructor wanted them to master.

By evaluating students' achievement between the final exam versus the individual tests around these topics, we were able to gather evidence on whether this was an effective method to reinforce important concepts of the course and improve overall student learning. An alternative view is that students could have been using these clicker reviews to maximize bonus points by following the majority opinion and not learning the concepts. However, throughout the course, the instructor would tell the students to focus on learning the concepts behind each of the questions. Table 1 and Table 2 show the examples of the question format given on the tests and the final. The question formats were designed based on the levels of Bloom's Taxonomy. Bloom's Taxonomy is a multi-tiered model that classifies learning objectives into different levels of complexity, from basic knowledge and comprehension to advanced evaluation and creation (Anderson & Krathwohl, 2001). The complexity level of each question pair is specified in the discussion section.

A paired-sample t-test was conducted to compare the student responses between the initial exams and the final exam for the course. Student performance data were analyzed based on students who participated in three initial tests and the final exam. Paired samples t-test was an appropriate design for this study as it assesses the difference

Format on the initial test	Format on the final exam
If the DNA strand 5′–GTACCGTC–3′ were used as a template, what would be the sequence of the transcribed RNA? A) 5′–GUACCGUC–3′ B) 5′–GACGGTAC–3′ C) 5′–CAUGGCAG–3′ D) 5′–GACGGUAC–3′ E) 5′–GUCGGUAC–3′	*If the DNA strand 5′–CAGTCAAG–3′ were used as a template, what would be the sequence of the transcribed RNA?* A) 5′–GTCAGTTC–3′ B) 5′–GUCAGUUC–3′ C) 5′–CTTGACTG–3′ D) 5′–CUUGACUG–3′ E) 5′–GUUCUGAC–3′
Answer - D	**Answer – D**

Note: A straightforward change in the design of a question

Table 1. Example of Question Pair 3

Format on the initial test	Format on the final exam
A partial diploid E. coli cell of $lacI^+lacP^+lacO^c$ $lacZ^-lacY^-$/ $lacI^-$ $lacP^+$ $lacO^+lacZ^-lacY^+$ genotype will synthesize: A) both *lacZ* and *lacY* gene products in the absence of lactose. B) neither *lacZ* nor *lacY* gene products in the presence of lactose. C) *lacZ* but not *lacY* gene product in the presence of lactose. D) *lacY* but not *lacZ* gene product in the absence of lactose. E) *lacY* but not *lacZ* gene product in the presence of lactose.	A partial diploid E. coli cell of $lacI^-$ $lacP^+lacO^c$ $lacZ^-lacY^+$/ $lacI^+$ $lacP^+$ $lacO^+lacZ^+lacY^-$ genotype will synthesize: A) both *lacZ* and *lacY* gene products in the absence of lactose. B) neither *lacZ* nor *lacY* gene products in the presence of lactose. C) *lacZ* constitutively, but *lacY* only in the presence of lactose. D) *lacY* constitutively, but *lacZ* only in the presence of lactose. E) *lacY* but not *lacZ* gene product in the presence of lactose.
Answer - E	**Answer - D**

Note: A change in the question that requires the students to have a more in-depth understanding of the concepts that the question addresses

Table 2. Example of Question Pair 7

	Concept and Bloom's Taxonomy	Statistically Significant Difference Performance	Performance Change
Pair 1	Meiosis - Analyzing	yes	positive
Pair 2	Replication – Applying	yes	Positive
Pair 3	Transcription - Applying	yes	positive
Pair 4	Pedigrees - Applying	yes	positive
Pair 5	Linkage - Analyzing	yes	**negative**
Pair 6	Epistasis - Analyzing	yes	positive
Pair 7	Bacterial Control of Gene Expression - Applying	**no**	positive
Pair 8	Imprinting - Applying	yes	positive
Pair 9	Eukaryotic Control of Gene Expression - Applying	yes	positive

Table 3. Statistical Significance Difference Findings for Question Pair Concepts

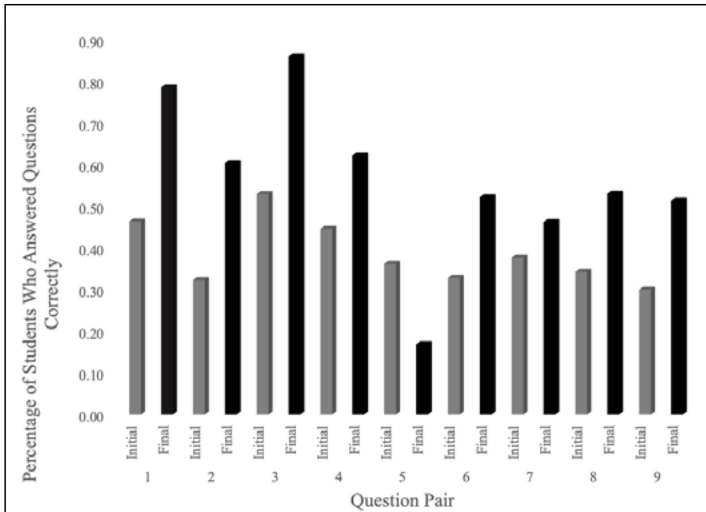


Figure 1. Students' Performance Differences in Exams

Pair	Concept and Bloom's Taxonomy	Mean Differences	t	df	Sig (2-tailed)
1	Meiosis - Analyzing	.32	5.58	120	.00
2	Replication - Applying	.28	4.67	120	.00
3	Transcription - Applying	.33	6.39	120	.00
4	Pedigrees - Applying	.18	3.04	118	.00
5	Linkage - Analyzing	-.19	-3.90	118	.00
6	Epistasis - Analyzing	.19	4.01	118	.00
7	Bacterial Control of Gene Expression - Applying	.08	1.45	116	**.15**
8	Imprinting - Applying	.19	3.16	116	.00
9	Eukaryotic Control of Gene Expression - Applying	.21	3.68	116	.00

Table 4. Question Pair Concepts and the Mean Difference of Scores

Paired	1	2	3	4	5	6	7	8	9
N	121	121	121	119	119	119	117	117	117
Chi-Square	23.67	17.56	29.25	7.84	12.41	13.08	1.68	8.48	11.29
Exact Sig (2-sided)	.000	.000	.000	.005	.000	.000	.193	.003	.001
Asymp. Sig.	.000	.000	.000	.005	.000	.000	**.194**	.004	.001

Table 5. McNemar's Test for the Significance of Change in Student Responses

between two paired results (Ross & Willison, 2017). Therefore, we attribute differences to the performance of students in the clicker process. Moreover, this test would also help us determine whether or not the clicker use strategy was effective.

Results

The results showed that there was a substantial difference in student performance from the initial exam to the final exam with the clicker intervention. The students' mean scores for eight out of nine-question pairs increased from the initial exam to the final exam. Table 3 shows the question pair concepts and the nature of the student performance. If students had higher scores on the final exam, the direction of the improvement was positive.

In 7 out of 9 concepts, students' performance improved from the initial exam to the final exam, indicating that the clicker use strategy helped students better understand the concepts and perform better in the final exam. Student performance declined in only one of the topics - question pair 5 (Linkage – Analyzing). The results also showed that the difference was not statistically significant even though students performed higher on the concept in question pair 7 (Bacterial Control of Gene Expression – Applying). This finding is meaningful and explained in the discussion section. Table 4 shows the question pair concepts, the mean difference of scores from the initial exams to the final exam, and each pair's significance level for better interpretation. Also, Figure 1 illustrates the differences in student performance scores from the initial to the final exam.

A non-parametric McNemar test was also conducted to compare the paired proportions. Table 5 shows the result that indicates significant changes in student responses from the initial exams to the final exam. The asymptotic p-value with continuity corrected was significant at $p < .05$ in all pairs except pair 7. In both cross tabs and non-parametric analysis, the results showed significant changes in students' performance from initial to final tests in all question pairs except for pair 7.

Discussion

In the current study, we examine student exam scores in initial tests and the final exam to measure the effectiveness of a particular application of clickers in a large biology class. We found meaningful differences in student performance between initial and final exams. Student scores increased significantly in the final exam for most of the question pairs examined, thus pointing to a positive impact of the clicker-use strategy described in this paper. For question pair 7, though we found no statistically significant difference in the compared scores, we did find student scores slightly improved from the initial to the final exam. There might be several reasons why the student did not score better in the final exam. During the peer-directed learning, more than 90% of the students agreed on an incorrect answer for question pair 7. Of all the bonus questions that were reviewed by peer-directed learning, this question elicited the highest percentage of students coming to an incorrect conclusion. It required further small group discussions beyond simply peer interactions for the whole class to arrive at the correct answer.

Thus, some peers were ultimately able to convince their classmates of the correct response, which generated bonus points for everyone. However, we hypothesize that the concept covered by question pair 7 continued to be difficult for students when posed in a slightly different question on the final.

We also found that the comparison result for question pair 5 is statistically significant, but it does not support our hypothesis that performance will be improved with the clicker intervention. The result showed a significant negative difference in student scores from initial exams to the final exam. This concept may be an excellent case for further investigation of ways to most effectively teach and assess student learning within the context of this course.

The clicker use strategies in a large biology classroom described here may have some other substantial and relevant implications for student learning. These are:

Time-on-task

Students in genetics class often lament the difficulty of learning and applying the concepts in this fast-paced course. However, students might come to class without the assumption that the practice of the material out of the classroom and continued reflection and revision of the material is necessary for mastery. By faculty dedicating time to students working through problems, wrestling with the answers, allowing the students to assist each other, and intentionally allowing the time it takes for the consensus of a correct answer, students understand the time that it takes to work toward mastery of a subject. When faculty practices are correlated with students' behaviors, students are more likely to work productively and thereby reap the potential benefits of learning (Keller et al., 2007). In addition, because a correct consensus was reached for all but one of the nine questions (question pair 5), students were also able to see that their effort had a reward of attaining the correct answer and achieving bonus points.

Integration of metacognition

The significant improvement in student performance data reported in this study indicates that students' metacognitive processes played an important role in classroom learning. As students were asked to come up with the answer for the question as peers, each student had the opportunity to deep dive into the question topic and reflect on their thinking through small group discussion. By the selection criteria for bonus review, the concepts treated with the peer-learning strategy were difficult concepts for students in this course. Smith et al. (2009) reported in their study of a genetics course for biology majors that "student learning gains were the greatest when students were asked difficult rather than easy questions". Knight et al. (2013) supported this finding in a biology course where students' discussion was compared with question difficulty (analyzed using Bloom's Taxonomy). When instructors asked higher-order questions, it resulted in more sophisticated student discussions and subsequent associated larger learning gains. While this study did not look at the quality of peer discussions, we can hypothesize that similar metacognitive processes were at play, as described by Smith et al. (2009) and Knight et al. (2013).

Other studies have found that when lectures incorporate clicker questions, the resulting peer interactions benefit students by focusing their attention on the task; developing independent, personally intuitive organization of concepts; and engaging in metacognitive self-evaluation (Duncan & McKeachie, 2005; Mayer et al. 2009).

Peer instruction allowed students to engage in general metacognitive activities such as organizing their thinking about question concepts; using appropriate skills to answer the question; assessing their understanding of the content; self-assessing their responses compared to others in the group, and evaluating the result. Improved metacognition may be helped students make the correct answer more convincing than the incorrect answer. Brady (2013) found that students' metacognitive processes and performance outcomes could be positively impacted through the use of peer instruction.

Repeated Practice

Students were given sample problems throughout the course to practice certain key concepts in homework, practice exams, standard clicker questions, and review sessions. By continually working on these same concepts, students were able to see that the types of questions they were given to work on actually did address the same concept and prepare themselves to answer a question about that concept correctly. Moreno and Kilpatrick (2018) found that students become more habituated through practice and repeated activities, and their self-efficacy improves. In addition, Mooi (2006) found that self-efficacy is significantly and positively related to course performance. Therefore, the repeated practice helped students to grasp the difficult concepts and identify the key points of the topic being tested, indicating that they were beginning to understand their knowledge of these topics. While this study did not measure the level of repeated practice students engaged in around the targeted concepts, the selection of questions for exam review likely indicated to students the relative importance of mastering those concepts.

The consensus-building that was practiced in the exam review sessions described here utilized peer-assisted learning with clickers as a time-effective way to provide students with repeated practice opportunities that could enrich their learning, reinforce complex concepts, and improve their performance. In addition, the clicker review sessions were a structured opportunity for peer-to-peer, peer-to-content, and peer-to-instructor interactions. Incorporating all these interactions repeatedly in the classroom, beyond the practice to the final exam, helped improve students' performance in the final exam.

Formative and Summative Assessment

The approach described in this study, with the application of clickers for promoting peer instruction, has important implications for considerations of both formative and summative assessment. Formative assessment is the process where inferences about student achievement are 'elicited, interpreted, and used by teachers, students, or their peers, to make decisions to make the instruction better in the future (Black & Wiliam, 2009). Clickers provided support for both instructors and students in assessing student learning through the formative assessment process during regular class sessions.

In the context of the current study, initially, the instructor identified the flagged questions from initial tests where more than 50% of students answered incorrectly. As these questions were fundamentally related to the main concepts of the subject, the instructor decided to improve student understanding of the concepts through facilitating peer instruction. As a component of consensus building through peer-assisted learning, clickers allowed students to rework flagged question concepts with peers and come to a consensus. Peer discussion on clicker questions facilitated students to think critically about concepts and helped improve their understanding.

The summative assessment occurred when the instructor examined the students' performance in the final exam at the end of the semester. Then, using the initial exam score as a benchmark or point of reference, the instructor measured students' overall performance in understanding the concepts and the course.

Limitations and Suggestions for Future Research

The current study is limited to only the exam scores on the selected topics that were repeated on the final exam as chosen by the instructor. Findings might have been different if student learning on a wide variety of concepts had been measured using clickers. The instructor used clickers primarily to motivate student engagement in the large lecture course and did not necessarily use them as a probe of student comprehension. Based on only students' test scores for selected topics, we examined the effectiveness of clickers in students' improved performance in the final exam. There may be different measurement choices to validate clicker effectiveness in students' performance, such as group dynamics and students' roles in interaction with the clicker questions that were not considered in the context of the current study. Pearson (2019) reported on improved performance data for a team-based clicker model with peer instruction where the cohort voted as a team versus individual student responses that also integrated live polling and discussion to create a more time-efficient instructional method.

In addition, our findings raised the question of why students demonstrate no gains in conceptual understanding of some concepts (question pairs 5 and 7). Although we provided a qualitative explanation of this in the discussion, further studies still need to address this question. Another possible issue that may arise in the current study is that a few pairs of students may be reluctant to engage in meaningful discussion with their peers and may simply be influenced by other peers to select the dominant answer choice. Therefore, we propose that future studies could address the following: Do students take different roles in peer discussion to interact with the clicker questions? How do group dynamics play a role in peer discussion answering clicker questions? How can an instructor minimize the gap between students' demonstrated understanding of the concepts as measured by an objective test and what they would ideally like the students to achieve?

Conclusion

The study's overall results indicate that students performed better on the final exam question than the initial exams, suggesting that some learning took place. Students in the class showed statistically significantly improved achievement for seven of the nine concepts tested. The application of clickers through facilitated peer instruction as a part of test review is a novel application that does not appear to have been reported elsewhere in the literature.

To summarize, the findings of the study serve as an effective evaluation of a case study of clicker usage in a large biology class. Specifically, we postulate that the described clicker-based, peer-assisted learning concept review led to improved student learning outcomes. This strategy could easily be applied to other large lecture classes that require assimilation and application of complex concepts. Moreover, the observed differences in students' performance from initial exams to the final exam may encourage other educators to implement a similar clicker usage strategy in their classroom settings.

Acknowledgments

We wish to acknowledge the inspiration of this method provided by Toni Weiss of Tulane University. In addition, we wish to acknowledge the instructor of the course, Mary Kroetz, who conducted the review sessions and designed the tests and final exam.

References

Addison, S., Wright, A., & Milner, R. (2009). Using clickers to improve student engagement and performance in an introductory biochemistry class. *Biochemistry and Molecular Biology Education, 37(*2), 84-91.

Alberts, B. (2000). Some thoughts of a scientist on inquiry. In J. Minstrell and E. H. van Zee (Eds,), *Inquiring into inquiry learning and teaching in Science* (pp. 3-13). Washington, DC: American Association for the Advancement of Science.

Alsup, J. (2004). A Comparison of Constructivist and Traditional Instruction in Mathematics. *Educational Research Quarterly, 28*(4), 3-17.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York, NY: Longmans.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability 21* (1), 5–31.

Brady, M., Seli, H., & Rosenthal, J. (2013). "Clickers" and metacognition: A quasi-experimental comparative study about metacognitive self-regulation and use of electronic feedback devices. *Computers & Education, 65*, 56-63.

Bruff, D. (2009). *Teaching with classroom response systems: Creating active learning environments.* San Francisco: Jossey-Bass.

Bruff, D. (2019). *Intentional tech. Principles to guide the use of educational technology in college teaching*. Morgantown: West Virgina University Press.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *Life Sciences Education, 6*(1), 9-20.

Chien, Y. T., Chang, Y.H., & Chang, C. Y. (2016). Do we click in the right way? A meta analytic review of clicker-integrated instruction. *Educational Research Review, 17*, 1–18.

Duncan, T. G., & McKeachie, W. J. (2005) The making of the motivated strategies for learning questionnaire. *Educational Psychologist, 40*(2), 117-128.

Einde, L. V. D., Lee, S. H., & Le, J. L (2012). *Incorporating clickers and peer instruction into large structural engineering classrooms*. Paper presented at American Society for Engineering Education, San Antonio, Texas, USA, held on 10-13 June.

Ferguson, N. H., & Chapman, S. R. (1993). Computer-assisted instruction for introductory genetics. *Journal of Natural Resources and Life Sciences Education, 22*(2), 145-148.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences,111*(23), 8410–8415.

Graham, R. D. (2013). Smart clickers in the classroom: Technolust or the potential to engage students? *Canadian Journal of Action Research, 14*(1), 3-20.

Hodges, L. C., Anderson, E. C., Carpenter, T. S., Cui, L., Feeser, E. A., & Gierasch, T. M. (2017). Using clickers for deliberate practice in large five science courses. *Journal of College Science Teaching, 47*(2), 22-28.

Hubbard, J. K. & Couch, B. A. (2018). The positive effect of in-class clicker questions on later exams depends on initial student performance level but not question format. *Computer & Education 120* (1), 1-12.

Kahu, E. R., & Nelson, K. (2018). Student engagement in the educational interface: Understanding the mechanisms of student success. *Higher Education Research & Development, 37*(1), 58-71.

Keller, C., Finkelstein, N., Perkins, K., Pollock, S., Turpen, C. & Dubson, M. (2007). Research based Practices For Effective Clicker Use. *AIP Conference Proceedings, 951*(1), doi.10.1063/1.2820913

Knight, J. K., Wise, S. B., & Southard, K. M. (2013). Understanding clicker discussions: student reasoning and the impact of instructional cues. *CBE Life Science Education, 12*, 645–654.

Körhasan, N. D., Ali Eryılmaz, A. E., & Erkoc, S. (2019). The role of metacognition in students' mental models of the quantization. *Science Education International, 29*(3), 183-191.

Kulesza, A. E., Clawson, M. E., & Ridgway, J. S. (2014). Student success indicators associated with clicker-administered quizzes in an honors introductory biology course. *Journal of College Science Teaching , 43*(4), 73-79.

Levy, D., Yardley, J., & Zeckhauser, R. (2017). Getting an Honest Answer: Clickers in the Classroom. *Journal of the Scholarship of Teaching and Learning, 17*(4), 104-125.

Lucus, A. (2009). Using peer instruction and i-clickers to enhance student participation in calculus. *Problems, Resources, and Issues in Mathematics Undergraduate Studies, 19*(3), 219-231.

Mayer, R. E., Stull, A., DeLeeuw, K., Almeroth, K., Bimber, B., & Chun, D. (2009). Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. *Contemporary Educational Psychology, 34*(2009), 51–57.

McDonough, K., & Foote, J. A. (2015). The impact of individual and shared clicker use on students' collaborative learning. *Computer & Education, 86* (2015), 236-249.

Mazur, E. (1997). *Peer Instruction: A User's Manual.* Upper Saddle River, NJ: Prentice-Hall.

Mazur, E.. & Somers, D. M. (1999). Peer Instruction: A User's Manual. *American Journal of Physics, 67*, 359. doi: 10.1063/1.881735.

Mollborn, S., & Hoekstra, A. (2010). A meeting of minds: Using clickers for critical thinking and discussion in large sociology classes. *Teaching Sociology, 38*(1), 18-27.

Mooi, T. L. (2006). Sel-efficacy and Student Performance in an Accounting Course. *Journal of Financial Reporting and Accounting, 4*(1), 129-146.

Moreno, R., & Kilpatrick, J. (2018). Student perceptions of self-efficacy in the foreign language classroom: A design-based research study. *EDeR. Educational Design Research, 2*(1). doi: 10.15460/eder.2.1.1214

Nagel, M. L., & Lindsey, B. A. (2018). The use of classroom clickers to support improved self assessment in introductory chemistry. *Journal of College Science Teaching, 47*(5), 72-79.

Nagy-Sadman, E. , & Desrochers, C. (2008). Student response technology: Empirically grounded or just a gimmick? *International Journal of Science Education, 30*(15), 2023-2066.

Patterson, B., Kilpatrick, J., & Woebkenberg, E. (2010). Evidence for teaching practice: Theimpact of clickers in a large classroom environment. *Nurse Education Toady, 30*(7), 603-607.

Pearson, R. J. (2019). Exploring peer instruction: Should cohort clicker responses appear during or after polling? *Journal of Chemical Education, 96* (5), 873-879.

Premuroso, R. F., Tong, L., & Beed, K. T. (2011). Does using clickers in the classroom matter to student performance and satisfaction when taking the introductory financial accounting course? *Issues In Accounting Education*, *26*(4). 701-723.

Ross A., & Willson, V. (2017). *Basic and Advanced Statistical Tests: Writing result sections and creating tables and figures*. The Netherlands: Sense Publishers

Roush, C., & Song, L. (2013). The impact of using clicker technology on classroom instruction: students- and teacher-s perspectives. *Candian Journal of Action Research, 14*(1), 21-37.

Shapiro, A. M., Sims-Knight, J., O'Rielly, G. V., Capaldo, P., Pedlow, T., Gordon, L., & Monteiro, K. (2017). Clickers can promote fact retention but impede conceptual understanding: The effect of the interaction between clicker use and pedagogy on learning. *Computers & Education, 111*, 44-59.

Smith, M. K, Wood, W.B., Adams, W. K,, Wieman C, Knight, J. K, Guild, N, & Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions. *Science, 323*, 122–124.

Smith, M. K., Trujillo, C., & Su, T. T. (2011). The benefits of using clickers in small-enrollment seminar-style biology courses. *CBE-Life Sciences Education, 10*(1), 14-17.

Stewart, K. (2009). Lessons from teaching millennials. *College Teaching, 57*(2), 111–117.

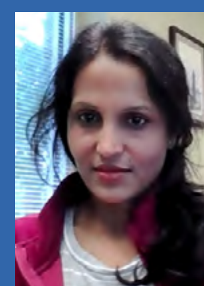
Topping, K. J. (2005). Trends in peer learning. *Educational Psychology, 25*(6), 631-645.

Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-based implementation of peer instruction: *A Literature Review, CBE—Life Sciences Education,14*(1), doi: 10.1187/cbe.14-11-0198

Weiss. T. (2017). Interactive strategies for engaging students in classes large, small and in between. Presentation at 2017 *South Alabama Conference on Teaching and Learning,* Mobile.

Wong, A. (2016). Classroom response system and student performance improvement: Local versus international students. *Journal of Teaching in International Business, 27*(4), 197-208.

Lipika Neshmin Arif has recently completed her Ph. D. in Business Administration from the University of South Alabama. She has been working as a Graduate Assistant at the Innovation in Learning Center (ILC) for five years. She completed her Masters in Instructional Design and Development (IDD) from the University of South Alabama and Masters in Workforce Education and Development with majoring in Human Resource Development from the Southern Illinois University Carbondale (SIUC). She also received her Master of Business Administration (MBA) and Bachelor of Business Administration (BBA) from the University of Dhaka, Bangladesh. Her research interest related to organizational behavior, leadership, and human resource development.



David S. Williams, Assistant Director of Course Development at the Innovation in Learning Center, facilitates development initiatives, such as implementation of module and course learning objects and support for effective use of instructional technology across course modalities. He also coordinates the use of instructional technology to support program and university assessment projects and serves on University Assessment Advisory Committee. David regularly collaborates with faculty on research projects, providing evaluation support and instructional design services. His research and interests focus on active and interactive learning in online courses, the role of self-efficacy in faculty assessment competencies, and program evaluation theory.

S. Raj Chaudhury is the Executive Director of the Innovation in Learning Center and USAonline at the University of South Alabama where he also holds a faculty appointment in the Department of Physics. The ILC works across the university to improve teaching through faculty development and support. Chaudhury will serve as the 2022-23 President of the International Society for the Scholarship of Teaching and Learning, almost two decades after he was initiated into SoTL as a Carnegie Scholar with the Carnegie Foundation for the Advancement of Teaching. His funded research and publications have been in the area of undergraduate STEM education reform, research based pedagogies and technologies and educational development.