

USING TECHNOLOGY TO ENHANCE THE IMPLEMENTATION OF PEER
DISCUSSION IN SCIENCE EDUCATION

by

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TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND	1
CONCEPTUAL FRAMEWORK.....	3
METHODOLOGY	9
DATA AND ANALYSIS	14
INTERPRETATION AND CONCLUSION	19
VALUE.....	21
REFERENCES CITED.....	23
APPENDICES	24
APPENDIX A: Sample Formative Assessment	25
APPENDIX B: Force and Motion Assessment	27
APPENDIX C: Student Perception Survey	37
APPENDIX D: Structured Student Interview Question	39

LIST OF TABLES

1. Research Matrix14

LIST OF FIGURES

1. Example Histogram of Student Responses	7
2. Frequency of Selecting Force and Motion Misconceptions	17
3. Student Perception Survey Results	18
4. Learning Catalytics Teacher Dashboard Image	20

ABSTRACT

The purpose of this action research project was to determine the impact of combining peer discussion with delivering formative assessments using a Classroom Response System (CRS) within physics education. The study was conducted with two sections of physics. Students in both sections of physics initially responded to conceptual questions independently and then responded following peer discussion. One section was provided option-based grouping for peer discussions while the students in the other section were grouped based on their initial responses, called evidence-based grouping. Using CRS formative assessment data to facilitate the instantaneous grouping of students with different responses facilitated the evidence-based grouping. Results revealed that evidence-based groupings enhanced the effectiveness of peer discussion, as noted by improved conceptual understanding and increased student motivation for seeking answers. However, the positive, moderate correlation between pre-assessment scores and post-assessment scores for both treatment groups showed the benefit of using technology to support peer discussion in enhancing learning.

INTRODUCTION AND BACKGROUND

I began my action research-based classroom project by exploring the effectiveness of formative assessments and methods for improving the quality of my assessments for learning. Prior to the study, my formative assessments consisted of entrance slips, which assessed understanding of the prior lesson, and exit slips, which assessed understanding of the current lesson. Additionally, I would conduct quick checks for understanding during the lesson by using white boards and thumbs-up or thumbs-down. While exit and entrance slips provided valuable feedback to guide instructional pacing, the task of reviewing and analyzing responses meant that students would receive feedback the following day. Conversely, white boards and thumbs-up or thumbs-down provided instantaneous feedback for instructional pacing. However, all students could not always view white board responses so the value of one student or group's response did not always enrich understanding for other students.

The idea for my action research project came while observing a fellow teacher using a Classroom Response System (CRS) or clicker. The CRS provided immediate feedback for student responses and allowed all of the students to respond anonymously. However, the CRS being used also had limitations, the technology was cumbersome and only allowed for simplistic student responses. Nevertheless, the benefit of instantly knowing what students understand was a valuable resource for helping the teacher tailor discussion prompts. Subsequently, I found a CRS program, which not only displayed multiple choice and true/false responses but also constructed responses, numerical responses and a many choice option. Assessment answers were also stored for each

question so the teacher could focus on interpreting the results and how to proceed with the instruction.

Given the initial success I viewed in my classrooms piloting the CRS, especially in terms of student engagement and motivation I decided to explore ways to further increase the effectiveness of the technology. While participating in a professional development opportunity I was exposed to the integration of using a CRS during the think, pair, share process. I was immediately drawn to the idea of using technology to simultaneously enhance the independent feedback and group discussion strategy of learning a new topic.

While teaching at the Oceanside High School (OHS) in Rockland, Maine I combined the use of a CRS with peer instruction for my action research-based project. The study was implemented during the Force and Motion Unit in two sections of physics. The sections of physics consisted of 26 eleventh and twelfth grade students. Regional School Unit #13 (RSU13) has a grade 8 – 12 high school with two campuses. OHS West comprises grades eight and nine while OHS East consists of students in grades ten through twelve, with campuses located in Thomaston, Maine and Rockland, Maine respectively. The consolidation of the former regional high schools, Rockland District High School and Georges Valley High School, began in September 2011 in an effort to develop a sustainable configuration in light of declining enrollment and a challenging economic climate (RSU13, 2011).

OHS serves a combined enrollment of 744 students and reports that greater than 55% of the students enrolled receive free or reduced-price lunch. Students at OHS reside in Knox County, with individual towns within the county being classified as rural. Knox

County and OHS have relatively low ethnic diversity, with 96% of students being Caucasian. Over the past two years, the climate of the school has been improving as OHS transitions from individual high schools to a consolidated RSU 13 (www.rsu13.org).

The purpose of the study conducted at OHS was to determine the impact of combining peer instruction with delivering formative assessments using a Classroom Response System (CRS) within physics education. The focus questions of the study are as follows:

- If formative assessments delivered using a CRS are used to guide peer discussion grouping will students improve learning?
- If formative assessments delivered using a CRS are used to guide peer discussion grouping will student understanding of content improve?
- If formative assessments delivered using a CRS are used to guide peer discussion grouping will student engagement improve?

CONCEPTUAL FRAMEWORK

Formative assessments, or assessments used to aid in student learning, serve the purpose of providing feedback of current learning. Additionally, all content areas demonstrate significant learning gains when students receive feedback from formative assessments. After reviewing 250 studies, Black and Wiliam (1998) found common threads for schools achieving improved student learning. Students in these schools had a clear understanding of what they were supposed to learn. Formative assessments were used to provide valuable feedback on their current levels in relation to the desired

learning target. Students also engaged in self and peer assessment so they were actively involved in the process of identifying their current learning level. Finally, formative assessments were used to help students identify the necessary steps to achieve the learning target or objective (Black & Wiliam, 1998).

In order for formative assessments to be effective in providing feedback, three components are necessary: First, students need to clearly understand the goal or standard. Second, students need to be able to assess their current learning in comparison to the expected performance for the goal or standard. Finally, students have to take the appropriate actions to accurately modify their work. Developing the student's ability to appraise their performance or skills compared to the desired outcome allows the student to close the gap in their learning. Therefore, student involvement in the feedback process through self-assessment is central to student understanding (Sadler, 1989).

The three components of effective formative assessments can also be relayed to students using the following three questions: "Where am I going? Where am I now? and How can I close the gap?" (Chappius, 2005, p.3). The first question relates to student understand of learning targets and how well the student is able to articulate what they are learning. By conducting formative assessments for each learning target students are able to gauge their current level of learning (Angelo & Cross, 1993). In addition to clearly stating learning targets, students need to be provided with exemplars. When students can identify features of a weak example of student work and components of a strong example they can appropriately reflect on the quality of their own work. However, students need opportunities to develop self-assessment skills by scoring sample student work, both weak and strong examples. Developing accurate self-assessment skills also helps

students answer the question of *where am I now*. To support student understanding of their current level, descriptive feedback is critical. Descriptive feedback provides quality information about how students are performing and how they can improve.

Finally, students need to be able to answer the question of *how do I close the gap* between their current achievement and where they need to be. Teachers can use formative assessments to focus on one component at a time such as developing a strong scientific claim. By developing the necessary skills incrementally, students can gain confidence in one area and then work to develop the next. Additionally, teachers need to develop the skill of student revision by using sample student work. Students can focus on one aspect of the sample work to improve thereby practicing a focused revision one component at a time (Chappius, 2005).

The three student questions help teachers keep students at the center of the process. The strategies systematically involve students by giving them opportunities to become actively engaged in the learning process. Students are central in identifying their current level through self-assessment and by using feedback to gauge understanding. One method for fostering an active learning approach is the use of Classroom Response Systems (CRS) to conduct formative assessments (Chappius, 2005).

CRSs are also called student response systems and are commonly referred to as clickers. Often questions answered by students are multiple choice or true and false, with student answers transmitted to the instructor's receiver. Student responses are instantaneously displayed using a histogram to show the distribution of answers (Beatty, Leonard, Gerace & Dufresne, 2006). Each student transmission is anonymous to the class yet can be recorded and identified by the instructor, making the technology useful

for both formative and summative assessments. The use of CRSs not only integrates technology within the instruction but also facilitates instantaneous feedback on student understanding. Closing the feedback loop within the instruction gives students an opportunity to reflect on their learning and to refine their understanding within the lesson (Caldwell, 2007).

The technological advantage of implementing formative assessments through CRSs has led to increased student performance, in addition to improved student and instructor attitudes (Caldwell, 2007). A study conducted by Addison, Wright and Milner (2009) in an undergraduate science course showed that students using the clickers demonstrated the highest proportion of students receiving an A or A- than had been recorded in the previous five terms. In comparison to other sections taught without the use of clickers, the achievement of students using clickers was statistically significant. Student attitudes were also positive in the section using clickers, with student perceptions showing the CRS helped them to enhance their learning and understanding of the material being taught. Finally, students perceived clickers as beneficial with regards to their student engagement and involvement in class. A majority of students also recommended CRS use in future courses (Addison et al., 2009). Gains in enthusiasm perceived by students were also found in other university studies (Herreid, 2006).

A review of multiple case studies identified that the critical feature of the CRS is how instructors are using feedback to foster an interactive environment, asserting that feedback is the key. Furthermore, the feedback for the students and teachers is more authentic than attempts to assess student understanding through traditional questioning methods. With traditional methods, students may alter their response based on their

peer's answer or simply not raise their hand. The effectiveness of CRSs correlates to challenging students each and every step of their learning, keeping students at the center of their learning (Herreid, 2006). Draper, Cargill and Cutts (2002) found that CRSs provide both the student and instructor the key advantage of receiving immediate feedback. By using closing the loop on the feedback cycle, the CRS helped students determine their level of understanding and aided instructors in tailoring instruction within the lesson.

One feature of the CRS is the histogram display of student responses, which aids in identifying student misunderstandings as well as content mastered (Figure 1). Student responses revealing a high level of misconceptions or incomplete understanding can guide future instruction. When Mazur (1997) identified low levels of understanding using the CRS, he asked students to discuss the question with a peer or group of peers, promoting social learning. Mazur stressed that using CRSs formatively improved student engagement and improved learning by providing valuable feedback to students and the instructor. Conversely, mastery of a problem also allows the students to provide valuable information for guiding instructional pacing.

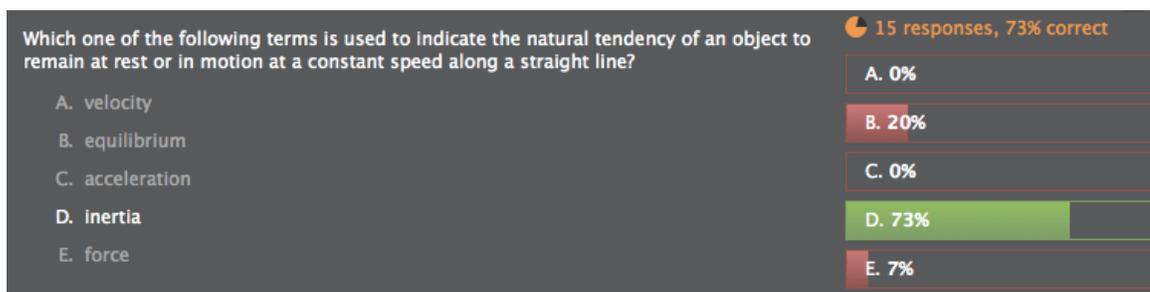


Figure 1. Example histogram of student responses.

Mazur's (1997) use of the CRS allowed the use of technology to be integrated with the effective instructional technique of peer instruction. When students are actively

involved in their learning through collaborative learning, such as instructing their peers, they successfully enhance their analytical and problem solving skills (Johnson& Johnson, 1987). Using the CRS with peer instruction enables students to respond anonymously to a discussion prompt, enabling independent thinking, and then students can explain their reasoning to another student or small group of students. Subsequently, after students work through the question cooperatively, with the instructor interceding in conversations as needed, the same question can be polled using the CRS. Crouch and Mazur (2001) analyzed formative assessment data in an algebra-based physics course that implemented peer instruction and compiled student responses for the entire semester. The research indicated a significant increase in content understanding, with 32% of the student responses changing from an incorrect to a correct response after peer discussions. However, the study also found that a threshold of 35% correct responses was needed for peer instruction to support learning and that a 70% or greater number of correct responses did not necessitate peer instruction. Mazur and Crouch (2001) also contend that while the peer instruction is not dependent on electronic forms of data collection, the ease of compiling data and maintaining anonymity are clear benefits. The study did not address the challenges a teacher would face trying to determine the percentage of correct responses when polling students with traditional methods of formative assessment.

When comparing polling techniques such as flash cards to the CRS, Lasry (2008) found no significant gains in conceptual understanding when both techniques were combined with peer instruction. While flash cards and the CRS close the feedback loop within the lesson, instructional advantages were identified for the CRS when comparing the time required for teachers to provide student feedback. Additionally, the ability to

store and later retrieve student data provides teachers with opportunities to reflect on their instructional techniques and assessment questions. The study indicated no correlation between the use of a CRS and the effectiveness of peer instruction; however, the initial polling results were not used to determine peer instructional groupings. The research simply indicates the conceptual gains from polling before and after peer instruction (Lasry, 2008).

Evidence strongly supports the use of structured formative assessments, with students actively engaged and invested in their learning (Black & William, 1998). Ideally, students need to be involved in determining their goal, assessing their current understanding and knowing how to narrow the gap between the two (Chappius, 2005). Instructional techniques using the CRS demonstrated ease of data collection and dissemination of feedback, closing the loop on the feedback cycle within the lesson (Mazur & Crouch, 2001; Draper et. al.,2002). Further research has indicated the combination of peer instruction and formative assessments to be effective in improving conceptual understanding (Lasry, 2008).

METHODOLOGY

During the Forces and Motion unit, junior and senior students from two sections of the same physics course were instructed using peer discussion combined with the use of a CRS ($N=26$). The type of Computer Response System used during the unit was Learning Catalytics (LC). LC is a software program that allows questions to be transmitted to students using a handheld device or computer through the Internet. Questions can be formatted to allow for numerical, textual and graphical responses.

Additionally, aggregate responses can be displayed directly on student computers for immediate feedback. LC was used to implement formative assessments of content knowledge, with questions relating to both conceptual understanding and problem solving ability (Appendix A). Section A students received option-based treatment, which involved responding to the formative assessment questions using LC with students being allowed to choose their partner(s) for peer discussions. Evidence-based treatment for students in Section B involved using the formative assessment data obtained from LC to intentionally group students with different initial responses during peer discussion. By comparing student learning gains, conceptual understanding and engagement, I examined the impact of evidence-based peer groupings. The research project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Two weeks prior to starting the unit, students were introduced to LC. Introductory activities demonstrated how the technology would be utilized during instruction and familiarized students with the multiple question formats and response methods. Following the LC introduction, students completed the Forces and Motion Assessment (Appendix B), developed using the American Association for the Advancement of Science (AAAS) assessment website. The AAAS site provided a test bank of multiple-choice test questions divided into topics and subcategories. Each test bank question aligned with the AAAS Project 2061 initiative developed to improve science education. The AAAS assessment tool provided pedagogical information on student understanding for correct responses and potential misconceptions for incorrect responses. Misconceptions were identified by topic, Force and Motion (FM), and the

misconception number, FM117 for example. Test bank questions provided data on how a sample of high school students responded nationally, with the percentage of correct responses identified. Questions were also classified into difficulty levels of easy, medium or hard. A total of 16 multiple-choice questions were selected from the test bank topic of Force and Motion. Out of the 16 questions, at least two questions were selected from each subtopic and only questions identified as medium or hard difficulty levels were chosen. Students completed the Force and Motion Assessment two weeks prior to starting the treatment unit and then upon completion of the treatment unit. Pre-assessment and post-assessment scores for individuals and sections were compared based on the number of correct responses. Additionally, the AAAS assessment tool identifies the frequency of selecting misconceptions based on the frequency of incorrect responses. Student misconception frequencies were compared for the pre- and post-assessment to determine the change in student misconceptions.

During the three-week Forces and Motion unit, formative assessments were delivered using LC three days per week for both sections of the physics course. Formative assessments consisted of three to five concept questions and included open response, multiple choice, many choice, diagrams and numerical responses. Students in both sections responded to concept questions independently and the initial responses were not displayed nor discussed with the class. Subsequently, students in the option-based treatment group, Group A, were asked to discuss the question with another student in the class and respond to the same question following peer discussion. For students in the evidence-based treatment group, Group B, the same concept question was independently answered; however, peer discussion groupings were determined based on

the data collected from LC. Students in the evidence-based groupings were intentionally matched with one or two students in the class who provided different responses to the question, when possible. Evidence-based groupings were not restricted based on proximity and at times lead to groupings with students from opposite sides of the classroom. For both treatment groups, student responses were viewed following peer discussion through a bar graph displayed on student computers. Student responses prior to and following peer discussion were analyzed to determine the learning gains for both the evidence-based peer groupings and option-based peer groupings. Other methods of formatively assessing students were not implemented during the Force and Motion unit.

Upon completion of the Forces and Motion unit, students were given the Force and Motion Assessment as a post-assessment. Pre-assessment scores were compared to the post-assessment results to measure conceptual understanding. A Spearman's Correlation Test was conducted for each session to determine if a linear relationship existed between the pre- and post-test scores. The correlation coefficient for the two ordinal variables was categorized as strong, moderate or weak relationship, with 1.0 being the strongest relationship between variables. The change in the misconception frequency was also calculated using the pre- and post-assessment.

Both classes were administered a Student Perception Survey (Appendix C), a post-attitudinal survey. Surveys were scored using the following Likert-scale: 5, *strongly agree*; 4, *agree*; 3, *neutral*; 2, *disagree*; 1, *strongly disagree*. The Student Perception Survey was administered to determine student views about how peer discussion combined with the new technology could help engage them in class, assist in their understanding of content and aid in overcoming misunderstandings. Participation in the

Student Perception Survey was anonymous and voluntary. For analysis, the categories of *strongly agree* and *agree*, in addition to *strongly disagree* and *disagree*, were collapsed and analyzed using the Fisher's exact test to determine if student responses were dependent on the treatment. The results of the Fisher's exact test showed the probability of the categorical data being associated with or dependent on the treatment.

Following the survey, ten students representing varying ability levels from both sections were asked to participate in an informal interview using Structured Student Interview Questions (Appendix D). The informal interviews were used to clarify and provide further detail regarding the anonymous Student Perception Surveys. Throughout the Forces and Motion unit in both sections a teacher journal was used to record student behaviors, attitudes, levels of engagement and observations made while combining LC with peer discussion. The data collection methods are summarized in Table 1.

Table 1
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3	Data Source 4	Data Source 5
If formative assessments delivered using a CRS are used to guide peer discussion grouping will...	Pre- and Post Assessment	Post Survey (using Likert scale)	Structured Student Interviews	Teacher Journal	LC Formative Assessment (pre- and post-discussion)
... students use peer discussion to improve learning?		X	X	X	X
... student understanding of content improve?	X	X	X		X
... student engagement improve?		X	X	X	

DATA AND ANALYSIS

Analysis of the Forces and Motion Assessment pre- and post-test results for treatment Group A, which received option-based peer instruction grouping facilitated by a classroom response system, showed a 39.5% increase in test scores. Treatment Group B, which received evidence-based peer instruction grouping facilitated by a classroom response system, showed a 49.7 % increase in test scores. There is a moderate, positive correlation ($r = 0.42$, Spearman) between the pre- and post-test scores for both treatment groups ($N = 26$). Additionally, both treatment groups had a statistically significant shift from pre-test to post-test scores, with a p -value from the Wilcoxon signed rank test of

0.005 and 0.001 respectively for the option- and evidence-based grouping. With 95% confidence, the difference in the center of the distributions was between -43.0% and -15.5% for option-based grouping; and between -52.0% and -29.9% for evidence-based grouping. The center of distribution represents the amount of improvement in assessment scores in each class. Therefore, the null hypothesis is rejected, providing strong evidence to support the combined use of a CRS with peer-discussion regardless of peer grouping structure. The Wilcoxon signed rank test was conducted due to the negatively skewed distribution of test scores for both sections, which was an expected result given that both treatment groups represented students in an upper-level course.

Peer-discussion responses were evaluated for both treatment groups by comparing the percentage of correct answers for the independent thinking responses and the peer-discussion responses for each conceptual question. Treatment Group A, with option-based peer discussion grouping, showed an increase of 12.4% after peer-discussion. Treatment Group B students, with evidence-based peer discussion grouping, showed an increase of 23.7% after peer-discussion of conceptual questions. Conceptual question responses, prior to and after peer-discussion, were statistically analyzed through a Wilcoxon signed rank test given the small sample size and abnormal distribution. The Wilcoxon signed rank test showed a statistically significant shift from individual to peer-discussion responses for the evidence-based grouping only ($p < 0.01$). With approximately 95% confidence, the median for the distributions of evidence-based grouping are between -34.0% and -14.5%. Conversely, the shift in the option-based grouping distribution was not statistically significant. The null hypothesis is rejected for option-based grouping that

the shift in distributions was not equal to zero. In other words, the evidence-based peer grouping showed a statistically significant increase in conceptual question responses.

Self-perception survey results showed that 85.7% of evidence-based grouping respondents felt that discussing CRS questions with their peers helped them better understand the content, compared to 45.4% of option-based grouping respondents. A Fisher's Exact Test showed that the survey responses for evidence-based compared to option-based grouping had statistically different distributions, p -value = 0.04. Therefore, survey responses showed that having a positive perception of peer discussion was dependent on peer-discussion grouping.

The Force and Motion Assessment conducted pretreatment also identified four misconceptions in student understanding that exceeded a frequency of 20% in at least one section. Specifically, students in both sections selected answers stating that an impelling force can become part of an object, (FMM114) demonstrating a misconception. After the treatment unit, the post-test frequency of choosing misconception FMM114 decreased by 69% and 77% for option-based and evidence-based grouping respectively. Questions relating to this force and motion concept asked students to identify the forces acting on an object after being rolled or shoved off a table and prior to hitting the ground.

The second misconception demonstrated that students felt a constant force was needed to keep an object moving at a constant speed (FMM129). The frequency of misconception FMM129 dropped by 22% for option-based grouping and 36% for evidence-based grouping post-treatment.

Students also selected the misconception that a constant force was needed for objects to move with constant velocity (FMM102). After the treatment unit, the

frequency of selecting FMM102 was reduced by 4% for option-based grouping and 20% for evidence-based grouping.

The last two misconceptions selected related to nonzero net forces acting upon an object, with students stating that an object's motion would initially speed up (FMM117) or slow down (FMM125) and then level off depending on the direction of the object's motion. Students in the option-based grouping reduced the frequency of choosing FMM117 and FMM125 by 18% and 22% respectively. Students in the evidence-based grouping decreased the frequency of selecting FMM117 and FMM125 by 22% and 36% respectively. All misconceptions identified related to Newton's First Law of Motion. Overall, the Force and Motion Assessment showed a decrease in the frequency of choosing misconceptions by 58.4% for Group A, option-based, and 73.8% for Group B, evidence-based grouping (Figure 2).

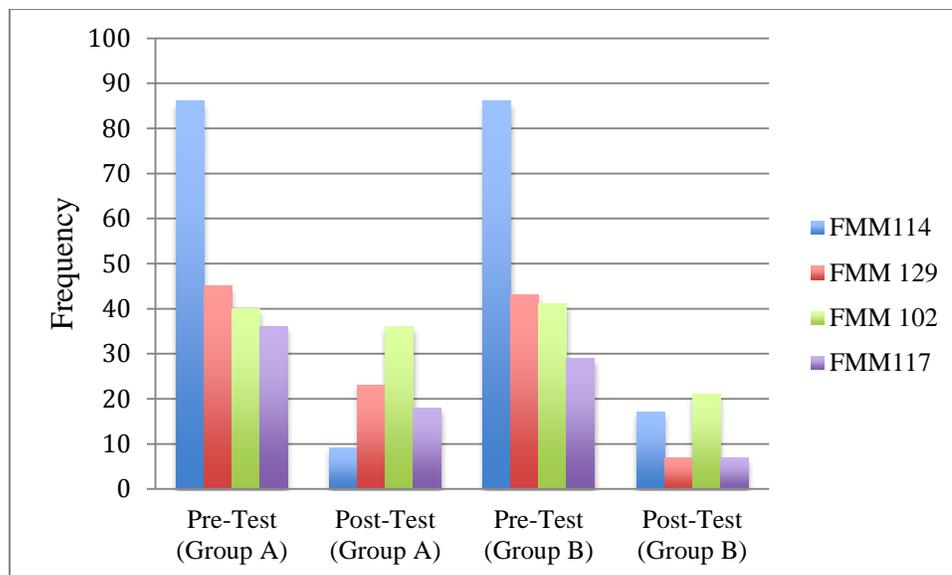


Figure 2. Frequency of selecting force and motion misconceptions on the pre- and post-force and motion assessment.

Note: FMM114: An impelled force can become part of an object; FMM129: A constant force was needed to keep an object at constant speed; FMM102: A constant force was needed for an object to move at constant velocity; FMM117: A nonzero net force results in an object speeding up and then leveling off in speed.

The Self-perception survey results showed that 45.4% and 92.5% option-based and evidence-based grouping respondents, respectively, felt that their performance on peer discussion questions motivated them to seek clarification on their own understanding of the material. The Fisher's Exact Test showed that survey responses for treatment Group B compared to treatment Group A had statistically different distributions (p -value=0.002). In other words, the survey responses provide strong evidence that seeking clarification of understanding depended on peer-discussion grouping.

Finally, 93.5% of evidence-based grouping respondents enjoyed using a CRS combined with peer discussions, compared to 63.6% of the students in the option-based grouping. One student commented, "I like being able to talk to lots of kids during one class. There are so many ways to think about a question." The level of enjoyment in using a CRS combined with peer discussion was not independent of the peer grouping structure as evidenced by a Fisher's Exact Test p -value of 0.05. The Fisher's Exact Test was used to evaluate survey responses due low counts in collapsed response categories, Agree-Neutral-Disagree (Figure 3).

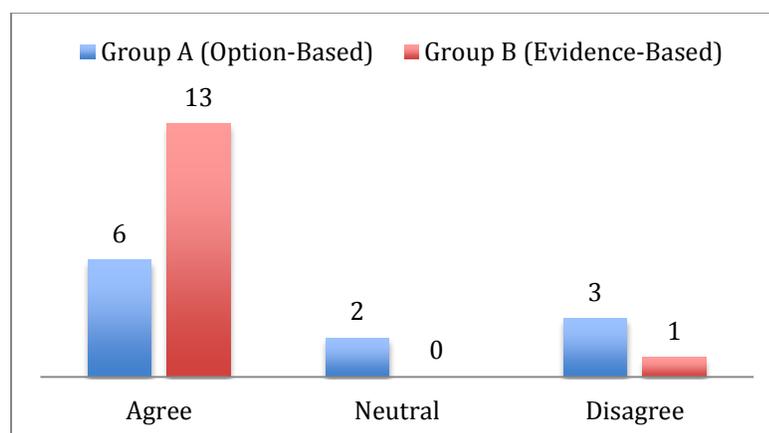


Figure 3. Student perception survey for whether student enjoyed using the CRS combined with peer instruction ($N = 25$).

INTERPRETATION AND CONCLUSION

Students grouped using evidence from formative assessment questions for peer discussion showed greater conceptual understanding. Over the course of the treatment unit, student conversations during peer discussion were drastically different in the two treatment sections. While both groups of students would start conversations with the standard, “What did you get for an answer?” the students in the evidence-based grouping with different answers then had to proceed by asking, “How did you get that answer?” Students in the option-based grouping might choose a partner for peer discussion who selected a different response, however, this was not always the case. The evidence-based groupings provided an environment for higher-level thinking and for students to discuss their reasoning processes. In these situations, peer discussions of a question could last up to 130 seconds. However, if students had the same response, peer discussion could be as short as four seconds. With peer discussion in the evidence-based grouping, the average time students discussed their own thinking would be greater as noted by the need for me to prompt students at the two minute mark. However, this was not always the case in the option-based grouping. Additionally, in the option-based grouping students would collaborate with the same student the entire class period, which typically encompassed four conceptual questions. Students in the option-based grouping were not provided the same variety of student feedback, which could be a challenge if both students were struggling with the topic for the lesson. However, in the evidence-based grouping students would work with different students for each of the four questions. This appeared to provide opportunities for students to get up and move around the classroom, which helped keep students engaged with the group. Additionally, by working with a different

student for each question, student understanding could be challenged by the new perspectives and allowed students to collaborate with multiple students within one lesson.

Student interviews of the two sections showed that students in the option-based grouping found “it discouraging to see we got the question wrong so we would start to second guess ourselves.” In contrast, students in the evidence-based grouping stated they “enjoyed the chance to talk to lots of kids in the class” and did not place value on getting the questions correct. Students in the option-based grouping also felt the CRS was a disadvantage because “the change to internet-based was a big change and a totally different style than we had for the past 12 years.” However, both sections valued the anonymous display of answers, with one student stating, “I never felt singled out when I didn’t know the answer.”

The additional benefits of using technology for facilitating the peer discussion was the ability to “access LC (Learning Catalytics) at home,” said one student who would use the conceptual questions to review content for further understanding. The final benefit discussed by both sections was the fact that “I can’t hide behind other kids because you (the teacher) can tell if we don’t understand.” The CRS feature of knowing when a student responded to the question and how the student responded was used to keep students engaged in the lesson, which clearly helped students stay on-task. While the CRS provided anonymity it also provided a data base for tracking student understanding, with easy-to-interpret pie charts on the instructor’s dashboard showing red for incorrect responses and green for correct responses (Figure 4).



Figure 4. Learning catalytics teacher dashboard showing pie charts for each conceptual question.

VALUE

The effective integration of technology within education has the potential to help teachers better meet the needs of students. By engaging students in higher levels of thinking, facilitating multiple discussions on reasoning and problem solving peer discussion also has the potential to increase conceptual understanding. Therefore, the pairing of technology and peer discussion seemed like a logical way to improve my instruction. In the end, I witnessed rich student discussions, 100% participation by students and decreased frequencies of choosing responses that identified misconceptions. The success of combining peer discussion and the Computer Response System allowed me to see the power of peer instruction. Students often asked their peer how they solved the problem or why they drew a specific diagram, which provided an extra layer of feedback within the lesson. Students were also open to explaining their reasoning in different ways when their peer was unable to follow the logic being presented. As a teacher, this project allowed me to see my classroom transform from being teacher-focused to students valuing the opinion of their peers.

While the assessment scores of the two groups were not statistically different, the increased level of conceptual understanding that happens within the instruction has made this project beneficial to me as a teacher. In fact, since conducting this project I am now collaborating with a colleague on using the CRS in his classroom. From the perspective of physics education, students were able to discuss misconceptions and drastically improve their quality of understanding. Finally, having 100% of the students actively involving in a lesson is not easily accomplished, yet I was able to achieve this benchmark

for the entire treatment unit in both sections of physics. What more could a teacher ask for than a teaching strategy to promote active minds.

Conducting this project also helped me to gain confidence in using new educational strategies in the classroom. Trying new instructional techniques, even ones successful in other settings, can be a daunting experience. During the project students would feel frustrated by the new techniques being used in class, however, I had the benefit of seeing the improvements in their scores to help buoy me through the challenging times. In fact, I couldn't wait to share the results of the post-test results with each class to show how much they had learned during the unit. I wanted them, and myself, to know that change can be difficult but it also can lead to progress. Prior to conducting the project, I would reflect on new strategies but not in a systematic and objective fashion, instead I would evaluate my successes and failures internally. Often I would listen to the more vocal students, which during my project did not reflect the majority of students, as noted by the anonymous survey results. I now realize the power of evidence-based teaching and the effectiveness of using data to help reflect on how my students are learning, which in turn helps me be a better teacher.

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APPENDICES

APPENDIX A

SAMPLE FORMATIVE ASSESSMENT: CONCEPTUAL UNDERSTANDING
QUESTIONS

Sample Formative Assessment:
Conceptual Understanding Questions

1. A tire swing can be made by tying a car tire to a rope and then tying the rope to a tree branch. What are the forces acting on the tire in the tire swing shown below?
- A. Only the pull of the rope on the tire
 - B. Only the pull of earth's gravity on the tire
 - C. Both the pull of the rope on the tire and the pull of earth's gravity on the tire
 - D. Neither the pull of the rope on the tire nor the pull of earth's gravity on the tire.



2. Which of the following statements can be explained by Newton's first law?
- (A): When your car suddenly comes to a halt, you lunge forward.
 - (B): When your car rapidly accelerates, you are pressed backward against the seat.
- A. Neither A nor B
 - B. Both A and B
 - C. Only A
 - D. Only B
3. The net external force acting on an object is zero. Which one of the following statements is true?
- A. The object can only be stationary
 - B. The object can only be traveling with a constant velocity
 - C. The object can be either stationary or traveling with a constant velocity
 - D. The object can only be traveling with a velocity that is changing

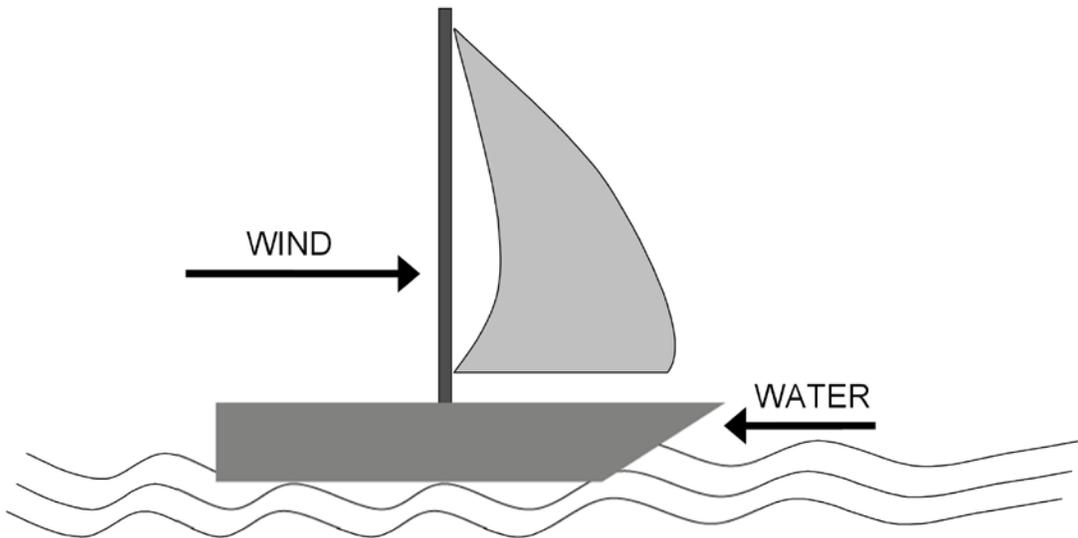
APPENDIX B

FORCES AND MOTION ASSESSMENT

Forces and Motion Assessment

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

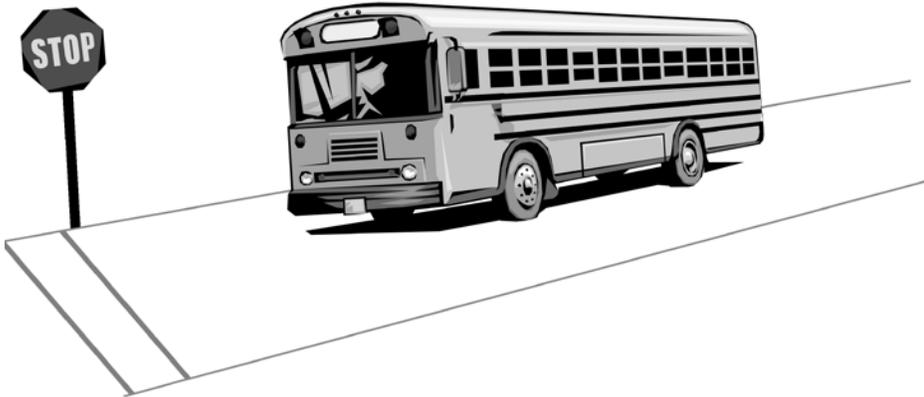
1. In the drawing below, the arrows labeled WIND and WATER represent forces acting on a sailboat during a certain period of time. During this period of time, the force of the wind on the sailboat is stronger than the force of the water on the sailboat. The directions of the arrows show the directions of the forces, and the lengths of the arrows represent the strengths of the forces.



Which statement describes the sailboat's motion while these forces are acting?

- A. The sailboat will speed up for a short time and then move at constant speed.
- B. The sailboat will speed up for a short time and then slow down.
- C. The sailboat will move at constant speed the entire time.
- D. The sailboat will speed up the entire time.

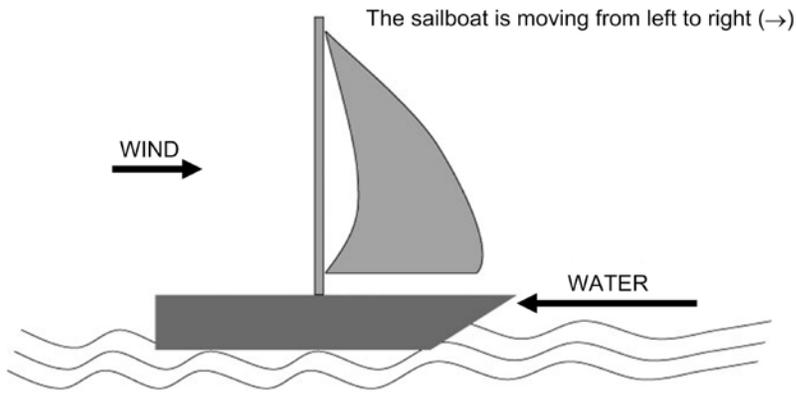
2. A school bus is slowing down as it comes to a stop sign.



Which of the following statements is TRUE about the forces acting on the school bus while it is slowing down but still moving forward?

- A. As long as the school bus is still moving forward, the forward force of the school bus has not run out.
- B. As long as the school bus is still moving forward, any forces moving it forward would have to be stronger than any forces slowing it down.
- C. If the school bus is slowing down, any forces moving it forward would have to be weaker than any forces slowing it down.
- D. If the school bus is slowing down, any forces moving it forward would have to be the same strength as any forces slowing it down.
3. A ball is rolled along and off a table. Which of the following acts on the ball after it leaves the table but before it hits the floor?
- A. Only the force of the earth's gravity on the ball
- B. Only the force the ball got from being rolled off the table
- C. Both the force of the earth's gravity on the ball and the force the ball got from being rolled off the table
- D. Neither the force of the earth's gravity on the ball nor the force the ball got from being rolled off the table

4. In the drawing below, the arrows labeled WIND and WATER represent forces acting on a sailboat. The directions of the arrows represent the directions of the forces, and the lengths of the arrows represent the strengths of the forces. The force of the water on the sailboat is stronger than the force of the wind on the sailboat the entire time.



Which statement describes the sailboat's motion while these forces are acting? Assume that the sailboat does not stop or turn around.

- A. The sailboat's speed will decrease the entire time.
 - B. The sailboat's speed will stay the same the entire time.
 - C. The sailboat's speed will decrease for a while and then stay the same.
 - D. The sailboat's speed will stay the same for a while and then decrease.
5. A person shoves an ice cube off a table. Which of the following acts on the ice cube after it leaves the table but before it hits the floor?
- A. Only the force from the shove on the ice cube
 - B. Only the force of the earth's gravity on the ice cube
 - C. Both the force of the earth's gravity on the ice cube and the force from the shove on the ice cube
 - D. Neither the force of the earth's gravity on the ice cube nor the force from the shove on the ice cube

6. An object is moving forward and no forces are acting on it. Every second, the object's speed is recorded. When the clock reads 0 seconds, the object's speed is 10 miles per hour (mi/hr). When the clock reads 2 seconds, a force begins to push the object forward. The force continues to act until the clock reads 4 seconds and then the force stops acting.

Clock →	0 seconds	1 second	2 seconds	3 seconds	4 seconds	5 seconds	6 seconds
Row A	10 mi/hr	9 mi/hr	8 mi/hr	8 mi/hr	8 mi/hr	7 mi/hr	6 mi/hr
Row B	10 mi/hr	10 mi/hr	10 mi/hr	11 mi/hr	12 mi/hr	13 mi/hr	14 mi/hr
Row C	10 mi/hr	10 mi/hr	10 mi/hr	11 mi/hr	12 mi/hr	12 mi/hr	12 mi/hr
Row D	10 mi/hr	11 mi/hr	12 mi/hr	13 mi/hr	14 mi/hr	15 mi/hr	16 mi/hr

Which row of the table could be a correct representation of the object's speed between 0 seconds and 6 seconds? Assume that if a change in speed has occurred, the change is shown in the table.

- A. Row A
- B. Row B
- C. Row C
- D. Row D

7. The table below gives the speed of an object every minute from 9:00 am to 9:06 am.

Time →	9:00 am	9:01 am	9:02 am	9:03 am	9:04 am	9:05 am	9:06 am
Speed →	10 m/s	10 m/s	10 m/s	10 m/s	11 m/s	12 m/s	13 m/s

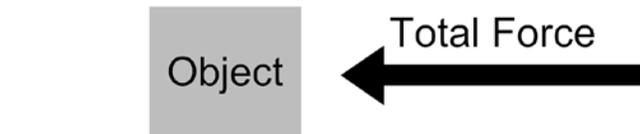
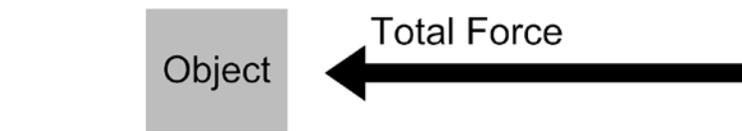
Which of the following sets of forces could cause this motion?

- A. From 9:00 am to 9:03 am, there is a single force of constant strength acting on the object. From 9:03 am to 9:06 am, there are no forces acting on the object.
- B. From 9:00 am to 9:03 am, there are no forces acting on the object. From 9:03 am to 9:06 am, there is a single force of constant strength acting on the object.
- C. From 9:00 am to 9:03 am, there is a single force of constant strength acting on the object. From 9:03 am to 9:06 am, there is a single force of increasing strength acting on the object.
- D. From 9:00 am to 9:03 am, there is a single force of constant strength acting on the object. From 9:03 am to 9:06 am, there is another constant force of greater strength acting on the object.

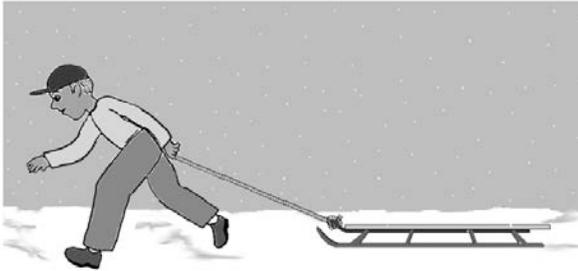
8. In the drawing below, the arrows labeled Force 1 and Force 2 represent two forces acting on an object. The directions of the arrows show the directions of the forces, and the lengths of the arrows represent the strengths of the forces.



Which total force is equal to the two forces acting on the object?



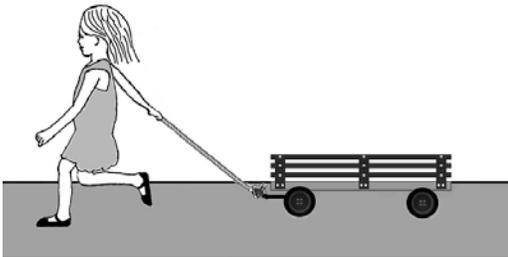
9. A boy is pulling a sled with a rope on level ground covered with snow. Assume he is running at constant speed and pulling on the rope with constant force.



Could the sled move faster than the boy is running?

- A. Yes, but only if he wasn't running fast.
- B. Yes, but only if the force of the pull on the sled was greater than the force of friction on the sled.
- C. Yes, but only if he was pulling the sled downhill and gravity was helping make it go faster and faster.
- D. No, because if he was pulling with constant force, the sled would have to move at a constant speed.

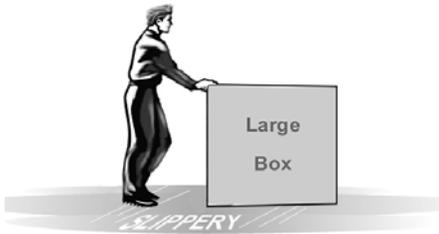
10. A girl is pulling a wagon on level ground. She is running at constant speed and pulling on the wagon with constant force.



Could the wagon move faster than the girl is running?

- A. Yes, but only if she wasn't running fast.
- B. Yes, but only if she pulled harder and harder.
- C. Yes, but only if the force of her pull on the wagon was greater than the force of friction on the wagon.
- D. No, because if she was pulling with constant force, the wagon would have to move at constant speed.

11. A man is pushing a box on a level surface. He is walking at constant speed and pushing with constant force. The surface is very slippery so the box slides easily, and he is wearing special shoes so he won't slip and fall.



Could the box move faster than the man is walking?

- A. Yes, but only if he didn't walk fast.
- B. Yes, but only if he pushed the box harder and harder.
- C. Yes, but only if the force of the push on the box was greater than the force of friction on the box.
- D. No, because if he was pushing with constant force, the box would have to move at constant speed.

12. Which of the following statements is TRUE about the motion of a cart that is being pushed on a level surface?



- A. The cart is moving at constant speed if the force of the push is constant and less than the force of friction on the cart.
- B. The cart is moving at constant speed if the force of the push is constant and is greater than the force of friction on the cart.
- C. The cart is moving faster and faster if the force of the push is constant and is greater than the force of friction on the cart.
- D. The cart is moving faster and faster if the force of the push is constant and the same strength as the force of friction on the cart.

13. What will happen to a hockey puck that is sliding along the ice if friction is acting?



- A. The puck will move slower and slower the entire time.
- B. The puck will move at a constant speed the entire time.
- C. The puck will move at constant speed for a while and then slow down.
- D. The puck will slow down for a while and then move at a slower constant speed.

14. A person is riding a snowmobile in a snowy field. Suddenly, a very strong wind begins to blow toward the oncoming snowmobile, and the wind continues to blow for a while. During the time the wind is blowing, the force of the wind is greater than the force that is moving the snowmobile forward.



What will happen to the speed of the snowmobile while the strong wind is blowing?

- A. The snowmobile will slow down for a while and then move at a slower constant speed.
- B. The snowmobile will move at constant speed for a while, and then slow down.
- C. The snowmobile will move at constant speed the entire time.
- D. The snowmobile will slow down the entire time.

15. Is it possible for an object to move at constant speed without a force pulling or pushing it?

- A. No, a constant force is needed to keep an object moving at constant speed.
- B. No, a force is needed to keep an object moving at constant speed, but it doesn't have to be a constant force.
- C. Yes, an object will move at constant speed unless a force acts to change its motion.
- D. Yes, an object will move at constant speed as long as the force inside the object doesn't run out.

16. What will happen to an object that is moving forward if a force pushing it backward is greater than the force pushing it forward?

- A. The object will move at constant speed for a while and then slow down and stop.
- B. The object will slow down for a while and then move at a slower constant speed.
- C. The object will slow down, stop, and then begin to move faster and faster in the opposite direction.
- D. The object will slow down, stop, and then begin to move at a constant speed in the opposite direction.

APPENDIX C

STUDENT PERCEPTION SURVEY

Student Perception Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

	Strongly Agree		Neutral		Strongly Disagree
1. Thinking about LC questions on my own, before discussing with people around me, helped me learn the course material.	5	4	3	2	1
2. Most of the time during peer discussion my group discussed LC question.	5	4	3	2	1
3. Discussing CRS questions with my peers helped me better understand the content.	5	4	3	2	1
4. The immediate feedback from peer discussion LC questions helped me determine my level of content understanding.	5	4	3	2	1
5. My performance on peer discussion question motivated me to seek clarification on my understanding of the material.	5	4	3	2	1
6. Knowing the right answer was the most important part of LC peer discussion questions.	5	4	3	2	1
7. Using LC combined with peer discussion helped me feel more engaged with the class compared to traditional lectures.	5	4	3	2	1
8. Combining LC with peer discussion was valuable for my learning.	5	4	3	2	1
9. Using LC with peer discussion improved my understanding of the content.	5	4	3	2	1
10. The combination of LC with peer discussion increased my feeling of belonging in the class.	5	4	3	2	1
11. LC combined with peer discussion increased my interaction with other students.	5	4	3	2	1
12. I enjoyed using LC combined with peer discussion.	5	4	3	2	1

APPENDIX D

STRUCTURED STUDENT INTERVIEW QUESTIONS

Structured Student Interview Questions

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. What were the benefits of using the CRS with peer discussion to assess your learning?
2. What were the disadvantages of using CRS with peer discussion to assess your learning?
3. Did using the CRS with peer discussion help you determine your level of content understanding?
4. Did using the CRS with peer discussion help you understand the content more effectively?
5. Did the CRS combined with peer discussion help you feel more engaged with the class?
6. Would you recommend using the CRS with peer instruction for future units? Why or why not?
7. Do you feel the teacher used the immediate feedback from the peer discussion responses to guide pacing and determine if reteaching was necessary?
8. Do you have any other comments?