AC 2012-4477: INCORPORATING CLICKERS AND PEER INSTRUCTION INTO LARGE STRUCTURAL ENGINEERING CLASSROOMS

Dr. Lelli Van Den Einde, University of California, San Diego

Lelli Van Den Einde is a tenure-track lecturer at UC, San Diego, and focuses mostly on undergraduate education in mechanics and design courses. Her past research was in the seismic design of bridge systems, but she is currently focused on assessing and improving engineering education pedagogy through technology. She has been the Faculty Advisor for UC, San Diego's Society of Civil and Structural Engineers (SCSE), a student chapter of the American Society of Civil Engineers, for the past two years. Additionally, Van Den Einde is also the Faculty Advisor for the ASCE Concrete Canoe competition team. She teaches a two-quarter technical elective course, which integrates not just the technical components of the concrete canoe project, but vital project management skills. Professionally, Van Den Einde is a member of ASCE and is currently the Secretary and Treasurer for the San Diego Earthquake Engineering Research Institute (EERI) chapter. Van Den Einde has her heart in the students' interests.

Samuel Holton Lee, University of California, San Diego
Ms. Jacqueline Linh Le, University of California, San Diego

Incorporating Clickers and Peer Instruction into Large Structural Engineering Classrooms

Abstract

Interaction and feedback are particularly challenging in large lecture environments, where class size limits student-faculty interaction. Clickers can be used to ensure students understand fundamental concepts by providing instant feedback to the instructor about student knowledge gaps or misconceptions [1]. The use of clickers also helps maintain students' motivation and engagement in what's going on in class, and provides an opportunity for Peer Instruction (PI). Clickers have been used since the 1980's in many science and humanities courses such as physics, biology, chemistry, history, mathematics, political science, law and psychology [2]. But based on current literature, the use of clickers has only recently been implemented in large engineering courses. This paper demonstrates the use of clickers in two large introductory Structural Engineering courses at the University of California, San Diego (UCSD). Implementation details and best practices are highlighted.

The assessment of overall impact on student learning using clickers will be presented through results a summative assessment of a post-course student survey. Additional evidence for improved student achievement will be presented qualitatively, including descriptions of student engagement in the material presented during lectures. Finally, the use of clickers to achieve Peer Instruction will be discussed in terms of its implementation, strengths, and limitations in the context of a large lecture hall environment. This paper asserts that the use of clickers supports an effective learning process that provides greater opportunity for students to get feedback from their peers and from the expert professor.

1. Introduction

In the traditional pedagogical approach, students are first exposed to the material in lecture, and then must learn challenging material through their textbook and homework, and ultimately show knowledge mastery through exams. This approach provides little opportunity for feedback during the learning process. With little activity in the traditional classroom, it is difficult to encourage student engagement and ensure critical thinking. This is contrasted with requiring that students are first exposed to and develop fundamental understanding of material on their own through reading assignments prior to lecture. This allows students to construct their understanding individually. This initial knowledge is then tested via clickers at the beginning of class to determine if students have adequately prepared to engage and learn in lecture. The instructor then presents challenging material through a combination of traditional lecture and clicker-based concept questions allowing students to test their understanding of the material [3]. Clickers provide the instructor with instantaneous feedback on whether students have mastered the concept, or if they have significant misconceptions, which could be addressed immediately. This process gives students the opportunity to receive expert help and explanation from the instructor when they need it.

Use of clickers during lecture also supports the implementation of Peer Instruction (PI) to complement the traditional lecture style. In PI, students first answer a question individually, and

then discuss the concepts with their peers. Students then answer the same or a similar question again, allowing them to change their answers based on the discussion [3]. Observations from case studies presented in this paper demonstrate that often peer discussion of clicker questions is an engaging and effective technique that increases student comprehension. Should PI cause the consensus answer to converge to an incorrect solution, then the instructor can discuss and correct the misconception.

1.1 Background for Clicker Technology in Classrooms

Clickers are also known as Audience Paced Feedback, Student Response Systems, Personal Response Systems, etc. Clickers have been used in the classrooms as a tool to take attendance, give anonymous surveys, and give instantaneous feedback [4]. The capability of returning feedback immediately and anonymously allows instructors to gauge the level of comprehension of the students on the spot [2]. Thus, clickers have primarily been used to facilitate PI [4]. Research shows that clickers have most commonly been utilized in physics and chemistry, and have recently expanded to the fields of mathematics, economics, biology, computer science, and engineering [2].

Clicker technology has been adopted by many instructors to overcome the ineffective traditional lecture approach of passive, one-way communication that often leads to students struggling to maintain continued attention [1]. Many institutions have adopted clickers to improve lecture style making it more active and personally engaging to primarily address high attrition rates in the sciences [5]. Trees and Jackson detail some of the difficulties of the traditional pedagogical approach when discussed in the context of a high-enrollment classroom, including the impersonal setting of large lecture halls for students and instructors alike, the passive nature of student involvement in the class, and a lack of practice time provided to students for their developing knowledge and skill sets [6].

Studies have shown that although the technology of clickers is straightforward, many students and instructors run into technical problems during their usage leading to negative attitudes [2][8]. Some technical problems encountered with clickers include students facing difficulties logging in and finding the network and instructors battling with software issues, how to display students' responses, and how to manage students' clicker grades [2]. Fies and Marshall also note that, due to student diversity – especially in a large lecture hall setting – student responses might vary widely with regard to the overall use of such instructional technology [7].

1.2 Peer Instruction and Clicker Efficacy

As expressed previously, the traditional pedagogical approach exposes students to the material first in lecture. Students then are required to learn the material through their textbook and homework. Finally, students show mastery of the knowledge through exams. Often times, instructors spend the entire lecture pouring information into student's minds. While the brain may act like a sponge in absorbing information, there is little activity in the traditional classroom to ensure student engagement and critical thinking [9].

The pedagogical approach of Peer Instruction (PI) has been shown to be effective in increasing student engagement in the learning process, and is especially applicable to lecture hall-type environments [9]. PI encourages all students, and not just the highly motivated and assertive students, to engage themselves in the lecture, to ask questions, and to apply the core concepts presented. In PI, students first answer a question individually, and then discuss the concepts with their peers. Students then answer the same or a similar question again, allowing them to change their answers based on the discussion [3]. The discussion between the first and second attempts to answer the question forces each student to defend their answer and question their peers'; thus, it actively encourages them to engage in lecture [11]. Mazur points out that the PI model is effective regardless of whether or not clicker-type technology is used to facilitate its implementation, but that use of a student response system is an advantageous addition as it aids in easy data mining and presentation for the class [7][11]. Additionally, the use of a response system allows student responses to remain anonymous, thus reducing an individual's hesitance to respond due to fear of embarrassment or humiliation in front of his or her peers [7]. Peer Instruction has been researched and well documented over the past two decades. Researchers of PI in the fields of math, physics, and chemistry have seen dramatic improvement in grasping course material through performance ConcepTest (a multiple choice question requiring deep conceptual understanding) during lecture and traditional exams [3].

Caldwell offers additional best-practice tips in her 2007 review of the technology. Her study summarizes the results of a number of reviews of the use of clicker technology, and supports the claim that such models increase classroom attendance, but only if the clicker questions are worth a significant enough portion of the students' grades [1]. In this it was found that clicker scores (attendance points or points for correct responses) should be worth between 10% and 15% of a student's grade in order to effectively increase attendance and preparation rates; the influence was found to be much less noticeable when these points were worth only 5% of the course grade [1]. Clicker use has also been shown to decrease attrition in student attendance over the duration of the term, and has been shown to improve student performance, although it is agreed that more research is needed in this area in order to deliver more conclusive data [1][12].

2. Case Studies

Pairing the instantaneous feedback capability of clickers with the use of PI enables an instructor to create an inverted classroom, to complement the traditional lecture style [3]. This approach was implemented in two large introductory Structural Engineering (SE) courses at the University of California, San Diego (UCSD). The two classes were taught by the same instructor during the 10-week fall quarter 2011. The courses were SE 1 (Introduction to Structures and Design), which ended up with 178 students, and SE 103 (Conceptual Structural Design), which ended up with 123 students. SE 1 serves as the very first Structural Engineering course (freshman level) and is a survey of the field of Structural Engineering, covering topics such as introduction to structural components of civil and aerospace structures, the design process, engineering ethics, and cost-benefit analysis. SE 103's objective is to introduce students (junior level) to the creative aspects of the design process and to the professional aspect of the industry.

2.1 Implementation Details

The model used in the two courses described herein was based on experience gained from other researchers (primarily in physics)[3]. Standard components of PI implementation that have been shown in literature to have a strong impact on learning were applied with the following features [10]:

- Reading was assigned before each class.
- Reading Quizzes were incorporated at the beginning of class to encourage students to complete the reading and test their understanding of it. Students only received points on these questions if they answered them correctly.
- Mini-lectures that presented material prior to a set of Concept Quiz questions were used throughout the lecture to identify if students were grasping the main concepts of the lecture.
- Clicker questions, like the physics ConcepTests [11] aimed to challenge deep understanding.
- Mathematical Problem Solving questions were also incorporated that posed a simple example requiring students to work together to set up the problem and come to a solution.
- The standard PI vote-discuss-vote format on clicker questions was used sometimes. Although it was intended to be used for most questions, due to time constraints in getting through lecture material, the format was sometimes dropped. Students initially had 30-60 seconds to answer a question individually; they then discussed the question with their peers for 1-2 minutes, and were expected to come to a consensus before answering again.
- Discussion groups were pre-assigned based on laboratory teams (approximately 4 students each) and it was encouraged that teams sit together during lecture. Some teams did, but in the end, most of the discussions were ad-hoc (e.g. discussion with people around you).
- The result of the first vote was always hidden from students before they entered into discussion. There did not seem to be a lack of interest in discussing the topic further without seeing the original results and it avoided students voting for the most popular answer when asked the second time.
- The correct answer was not indicated on the slide after discussion but was stated verbally by the instructor.
- In addition to explanations of the correct answer, in some situations, students were asked to provide reasonable explanations for why wrong answers were wrong.
- The instructor did not repeatedly present students with rationale and research results from physics showing the benefits of the PI model for learning. This was done during the introductory lecture but not throughout the course [1][11].

In both classes, the reading quizzes constituted 5% of the total grade in the class. The participation questions that consisted of Concept Quizzes and Problem Solving questions constituted 10% of the grade in SE 1 and 5% of the grade in SE 103 (a significant amount of lab work and team projects were required for this particular course). Reading Quiz questions counted right or wrong. However, all other clicker questions were only based on participation rather than performance (correctness) to encourage engagement. The downside to this was the possibility of

students clicking in just to get credit without really making use of the PI approach. This is discussed further in the best practices and instructor feedback sections.

Both courses used the Blackboard Learn 9.1 course management system in conjunction with the iClicker for mac software version 6.1 2, which was supposed to integrate easily (discussed further in the instructor feedback section). These are UCSD's supported software and systems.

2.2 Assessment Method

The techniques and procedures used to analyze the success of the implementation of clickers and PI in the two structural engineering courses were based on a mixed method approach, where qualitative and quantitative assessment strategies were used concurrently. The strategy of quantitative inquiry used in this assessment included post-surveys [13], which is discussed further in the results section. In addition to the evaluation of free response questions from the surveys, qualitative case-study observations of the implementation were made.

3. Results

The student surveys that were conducted included a number of questions requesting participants to rate their agreement on statements about the use of clickers in the SE 1 and SE 103 courses. The six response options used for these questions included "disagree very strongly," "disagree strongly," "disagree," "agree," "agree strongly," and "agree very strongly." For the purpose of presenting results, students answering in the affirmative were considered as those giving any of the answers of agreement with a given statement, and vice versa for negative answers (any form of disagreement). Additional breakdown of student response rates are provided where appropriate. The survey was compulsory for SE 1 as a homework assignment but was optional for SE 103 resulting in sample sizes for SE 1 and SE103 of 144 and 106, respectively.

For the most part, student responses for the two courses were well aligned, with few significant differences in responses for any given question. For this reason, the presentation of results here will focus on reporting relevant findings from both courses simultaneously, not attempting to discern the minute differences between the two. Relevant figures for specific survey questions may be referenced in the appendix, located by question number.

Question 1 of the survey was a "demographic" question about which courses students had used clickers in before. The question asked if students had used clickers in a computer science class at this school, a physics class at this school, a biology or chemistry class at this school, a psychology class at this school, some other class at this school, or at some other institution before. Results showed that significantly fewer students in SE 1 had previously used clickers as compared to SE 103 (refer to Question 1 results in the Appendix). This is probably due to the fact that SE 1 has a younger student population, on average.

3.1 Student Motivation and Engagement

A number of questions were posed to students in order to assess whether or not the use of the inverted classroom model and PI, facilitated by clickers, enhanced students' motivation to perform well in the course of interest. Survey questions (Questions 12, 15-18 in the Appendix found in Section 6.1) were developed to address the following primary points of inquiry:

- *Do clicker questions, and the immediate feedback that they give, aid in motivating students to improve their study habits and/or to seek to correct their misunderstandings of the material?*
- *To what extent does using clickers help to improve student engagement in large lecture hall environments?*

Table 1 shows the results for Questions 16-18 of the survey for each of the two courses. When asked whether their performance on reading quizzes motivated them to review the material, students from each class responded positively with 71.7 percent of students in SE 103 and 82.6 percent of students in SE 1 answering in the affirmative ("agree," "agree strongly," or "agree very strongly"). Nearly half of SE 1 students (46.5 percent) responded with "agree strongly" or "agree very strongly".

Table 1: Summary of Responses Regarding Reading Quizzes and Motivation

	Affirmative Responses	
	SE 1	**SE 103**
Reading quizzes motivated students to review the material	82.6 %	71.7 %
Performance on reading quizzes motivated students to change their study habits	77.1 %	67.9 %
Performance on peer discussion questions motivated students to seek clarification on misunderstandings	77.8 %	82.1 %
Clicker questions encouraged students to think critically about lecture material more than in comparison to traditional lectures	77.8 %	83.0 %
Clicker questions helped students pay attention in the lecture in comparison to traditional lectures	86.2 %	83.0 %

Responses were similar when students were asked whether their performance on reading quiz questions motivated them to change their study habits for future reading quizzes. In SE 103, 67.9 percent of students responded in agreement, while in SE 1, 77.1 percent of students did likewise (Question 17). Students were also surveyed on whether their performance on peer discussion questions motivated them to seek clarification on their misunderstandings of the material. For this, students in each class responded affirmatively at over a 75-percent response rate (82.1 percent for SE 103, 77.8 percent for SE 1). For each class, only a small percentage (13.2 percent for SE 103, 16.0 percent for SE 1) responded with "disagree," while an even smaller portion responded with "disagree strongly" or "disagree very strongly" (4.7 percent for SE 103, 6.3 percent for SE 1, Question 18).

Comparing student motivation and engagement between traditional lecture styles and those presented here (using an inverted classroom with peer instruction, facilitated by clickers) was another aim of the surveys. Students were asked whether using clickers in these courses encouraged them to think critically about lecture material more than in a standard course. For

this, 83.0 percent of SE 103 students responded affirmatively, while 77.8 percent of those in SE 1 did the same (Question 15). Students also responded positively when asked whether clickers helped them pay attention in this course compared to traditional lectures; SE 103 students responded affirmatively 83.0 percent of the time, while those in SE 1 did likewise 86.2 percent of the time (Question 12).

3.2 Student Learning and Achievement

A variety of questions were posed to students regarding how PI and the use of clickers aided in their learning in the course. Survey questions (Questions 3, 7, 8 and 10 found in the Appendix in Section 6.1) were developed to address the following primary points of inquiry:

- *Does peer-instruction, when facilitated by clicker use, aid in student learning?*
- *Do students who prepare for clicker quizzes and remain engaged in class perform better overall as compared to their classmates?*

First, when questioned as to whether thinking about clicker questions on their own, before discussing with the people around them, helped students to learn the course material, the overwhelming response was positive. SE 103 students agreed that this was the case 87.8 percent of the time, with SE 1 students responding 88.2 percent positively (Question 3). Responses were similar when students were asked whether discussing course topics with their seatmates in class helped them to better understand the course material; SE 103 students showed agreement at an 89.6 percent rate, while those in SE 1 agreed at a rate of 84.7 percent (Question 7). From these two questions it may be understood that it is actually the combination of allowing students to think on their own, then to discuss with peers, which helps them to at least perceive an enhanced learning of the course material.

With regard to PI and the resulting in-class discussion, student attitudes toward this lecture style's influence on their learning remained positive. When asked to rate their agreement whether they felt pretty clear about a topic by the time they completed a question and discussion, SE 103 students responded affirmatively 82.1 percent of the time, while those in SE 1 did so at a rate of 75.7 percent (Question 10). The lower numbers in SE 1 might relate to a need for further time allotted for discussion, which will be addressed in the Best Practices section. Students also saw the value in the immediate feedback that is provided during the discussion of in-class clicker questions. When questioned on whether the immediate feedback from clickers helped them to focus on weaknesses in their understanding of the material, students responded positively in both courses (83.9 percent agreement in SE 103, 90.2 percent in SE 1, Question 8). Due to the conceptual nature of these courses, it is critical that peer instruction and the inverted classroom have a strong, positive effect on students' ability to grasp course material.

3.3 Student Perceptions of Clickers

Students were surveyed to determine their perceptions on the implementation of clickers in the two courses investigated. A primary area of concern was the level of difficulty of the clicker questions used for reading quizzes and for in-lecture concept questions. Survey questions

(Questions 20, 21, 23, 24 and 26 found in the Appendix in Section 6.1) were developed to address the following primary point of inquiry:

- *What are students' perceptions on using clickers and, specifically, how clickers were implemented in these courses?*

When polled on difficulty level of such questions relative to what would be most appropriate in aiding in learning, most students believed that the question content was appropriate; 89.6 percent of SE 103 students and 92.4 percent of SE 1 students responded as such (Question 20). A small percentage of students from each class reported that questions were too hard (up to 9.4 percent of students in SE 103). This behavior is expected since students generally do not complain when problems are too easy.

Most students thought that the instructor gave enough time to read and understand the question before voting (89.6 percent for SE 103, 79.2 percent for SE 1) with small percentages reporting that the time was too short or too long (Question 21). Additionally, the majority of students also believed that the time allowed for discussion during the question was approximately sufficient (85.8 percent for SE 103, 77.1 percent for SE 1, Question 23). Similarly, when asked whether the time allowed for in-class discussion (after the vote) was adequate, results were similar (89.6 percent for SE 103, 72.2 percent for SE 1), though a significant proportion of students in SE 1 thought that the discussion time allowed was too short (19.5 percent total, compared to 8.5 percent for SE 103, Question 24). This is another implementation detail to be treated with care, as it is anticipated that the post-question discussion must be of adequate length for the feedback process to be useful; too short of a discussion time might altogether defeat the purpose of developing lectures that use clicker questions.

On the whole, students in both classes believed that the instructor adequately explained the purpose of using clickers (89.6 percent for SE 103 and 85.4 percent for SE 1), with a small portion of students responding that the purpose was explained somewhat well, but that they still felt unclear as to why it was being used (7.5 percent and 8.3 percent, respectively, Question 26).

3.4 Instructor Feedback

This was the first attempt to incorporate clickers and PI into the Structural Engineering classroom for this instructor. Several logistical and implementation issues arose. One of the key implementation details is the choice of clicker software, which is typically selected at the university level (iClicker in this case), and its interface with the course management system used by the university. During fall quarter 2011, in addition to using clicker's for the first time, the course management system at UCSD was completely overhauled to the Blackboard 9.1 version. This seemed to cause problems related to student registration of their clickers. While the registration process was supposed to occur automatically through the course management system, in the large lecture halls the synchronization seemed difficult, requiring the manual registration of a number of students into the system. This often led to the necessity to input grades from the clicker questions manually into the course management system gradebook, which was tedious considering the total amount of clicker questions asked throughout the quarter and the large number of students in each class.

Furthermore, the course roster in the course management system that assigns names to clicker identification values would not always synchronize so as students enrolled or dropped the course or got a new clicker because they lost their original one, it was impossible to constantly update the class roster and associated clicker IDs.

Also, the course management system automatically associated the clicker ID's to the student's email address. However, many students went directly to the iClicker website to register their clickers and when they were asked for their identification, the students inconsistently inputted either their email or the personal identification number (PID). This caused the results during the clicker sessions to not integrate properly since the course management system was looking for email addresses as the identifier not their PIDs.

The work around to all these integration complications with the course management system consisted of manually inputting clicker data to a separate spreadsheet and then uploading the grade data to the course management system, a very time consuming effort. Therefore, it is recommended to make sure that the course management software and automated response system software integrates well and that clear instructions about the registration process are provided to the students. Just because the tools say they integrate well, does not ensure that they do.

Another implementation issue was related to a limitation with the iClicker software, which was not robust enough to allow for the collection of data related to PI and inverted classroom that was targeted in the two case studies described in this paper. Specifically, this was related to grading the two types of questions differently (Reading Quizzes graded for correctness and Concept Quizzes graded for participation). The software allowed the instructor to identify a threshold of how often the student was required to click in to get full credit on the participation points. For example, if the student clicked in a minimum of 20% of the time, the software allowed the students to get full participation points. The software did not provide an option of identifying different types of questions that would be graded differently. Therefore, to work around this limitation, a class session was initiated for the reading quiz questions and then a new one was started for the remaining concept quiz questions requiring extra manual work for data integration. A more effective approach would be the ability to assign grading options per type of question in support of the PI method.

The iClickers were also used in laboratory sessions, which were challenging because you either had to start a new course session with the iClicker software for each laboratory section or continue the previous session. Either approach resulted in cumbersome integration of the clicker data into the content management system. If you started a new session for each lab, you had 5-10 files to integrate into the CMS (depending on the number of lab sections). If you continued the previous session, your results would show the total number of questions that were asked in ALL the laboratory sections with students only showing answers to the few that were asked during their particular lab section, requiring further manipulation of the data. While the iClicker is fairly straightforward to use, it currently is limited in functionality. With some improvements, the use of clickers and PI could be more successful.

Students perceived that the use of clickers and PI was successful in better engaging them in the learning process. However, to do it correctly requires full commitment by the instructor. In particular, recreating lectures around clicker questions is time consuming and must be done correctly to be effective. Instructors must remove a significant amount of traditional lecture material and try to create effective questions that would entice discussion that covers the same concepts as originally presented in a traditional lecture format. Reducing lecture time to provide ample time for discussion has proven to result in increased understanding of challenging topics and increased retention of the material [1]. Writing good clicker questions is not often easy for all subject matter and requires considerably thought on how to ensure primary concepts are learned through discussion.

> Preparing the right questions for clicker use is just as important as learning how to operate the technology. By writing effective questions, instructors will ensure a closer connection between clicker questions and course learning objectives [14].

Often due to time constraints, poor clicker questions are written for the sake of having clicker questions or the clicker questions are not used throughout the lecture but rather placed all at the beginning, which are proven to not be effective.

Additionally, it has been shown that simple questions can cause student boredom and resentment [1][15]. It is recommended that instructors take notes after their implementation of each lecture on which questions seemed to be effective in drawing out discussion and which were poorly constructed.

Furthermore, the instructor should focus on how the answers to the clicker questions are discussed and use it as a learning experience. Sometimes the discussion of several of the wrong answers helps identify common misconceptions of the key topics.

Key to the success of the PI methodology is providing appropriate reading assignments to the students before coming to class. For courses that follow a traditional textbook, this may seem quite easy. For the two courses described in this paper, textbooks are not used, so it was challenging finding appropriate reading material that was not too technical or time consuming to read. It was also challenging getting students to read before coming to class.

Another challenge included encouraging and facilitating classroom discussion. SE 103 seemed considerably more vocal during discussions than SE 1, which could be attributed to the fact that SE 103 consisted of juniors and SE 1 primarily consisted of underclassmen. Furthermore, SE 103 students seemed to sit with their lab teams whereas SE 1 students sat independently although they were encouraged to sit with their teammates. Also, SE 1 met from 7:00-10:00pm once a week, so the students may have been tired.

4. Discussion

4.1 Best Practices

Observations from the case studies presented demonstrate that peer discussion of clicker questions is an effective technique in motivating and engaging students to increase comprehension. Based on this experience report and the student surveys', the following best practices are recommended:

- Be proficient with the clicker software and the administration of clicker questions, and be familiar with the resolutions to common technical problems (changing frequency, etc.) prior to the first classroom session. Because technical issues typically arise during the first couple of class sessions, practice several clicker questions with the students before corresponding their responses to grades [2].
- Present clickers, PI, and their integration into the course; and explain their value in the course.
- Reinforce the value of comprehension by awarding participation points rather than performance-based points for discussion questions.
- Develop reading quiz questions based on assigned reading. Utilize the results from these questions to assess the overall level of understanding and preparedness of the students to engage in discussion in lecture.
- Develop conceptual discussion questions requiring critical thinking and application of the presented material. Include answers derived from misconstrued concepts and answers such as 'Depends' as one of the multiple-choice answers as distracters; they lead to valuable discussions.
- Encourage the classroom to be vocal, "it should be loud in here! Talk!". Partake in the discussions by roaming the room and facilitate small discussion groups. Sometimes, these discussions will roar. It is time to wrap up when the volume begins to lower or approximately 75% of the class has clicked in.
- Go over the incorrect answers in addition to the correct answer. Ask 'Why is B wrong?' Make it a classroom wide discussion to correct misunderstandings and reaffirms the answer.
- A picture is worth a thousand words. Show histograms from the individual vote and the post discussion vote together especially when they show great improvement. The first time the students see the effectiveness of their discussions, they will be amazed and motivated to continue in peer discussion. [1][10]

4.2 Pitfalls to Avoid

Based on the experiences presented in this paper, the following recommendations are suggested:

- Because the concept quizzes were only graded based on participation, it was tough to avoid students who would "just click in" to get credit rather than spend time really engaging with the material. So there is a fine balance between incentivizing the use of clickers (giving points for participation) versus ensuring that the objectives of using clickers for PI are not lost. Furthermore, once you incentivize participation, you have to police the class and make sure they are not clicking in for their friends or are not coming for the first 10 minutes to get reading question credit and then leaving.

- The wording of clicker questions can impose an instructor bias. To be effective, instructor should either not read the question aloud or do so without providing any clues to the solution so as not to impress a bias.
- Students often forget their clickers or the battery dies. Some clicker systems offer a "loan clicker" option, which allows students to borrow a clicker for the session. In the two courses presented, the instructor did not offer the loan clicker option, but was too lenient in allowing students to handwrite their answers to get credit. This resulted in the manual input of clicker grades throughout the quarter, which was very time consuming. It is recommended to have a zero tolerance policy. If students do not bring their clickers or do not have extra batteries, they miss out on the points. Students should take responsibility of their learning.

In general, clickers and PI in engineering has not been used that often [16]. In the two structural engineering courses its implementation was perceived by the students to be extremely successful in engaging them and ensuring that they understand fundamental concepts. It provided the instructor with instantaneous feedback about student knowledge gaps or misconceptions, allowing the instructor to adjust lectures on the fly. It was also extremely fun to conduct lectures, especially when the volume level during discussion roared.

However, to convert a traditional class to one with clickers and PI requires a lot of work the first few times in terms of overhauling lectures and developing effective clicker questions. It is recommended that instructors should focus on incorporating clickers and PI into one course per term due the significant amount of work required. The two courses described in this case study are not traditional civil engineering core courses and therefore the instructor had to develop all clicker questions from scratch. However, there are many common classes across institutions such as statics, dynamics, and solid mechanics where a repository of clicker questions would be extremely beneficial to instructors. While some questions are instructor specific, this would eliminate the amount of work required to develop quality questions. Some instructors have already begun to share their material.

Additionally, the time allotted for discussion of clicker questions in the PI framework reduces the effective amount of lecture time, resulting in an increased chance that the instructor is not capable of fully covering the material in the original course syllabus. In the two case study courses, this impact was negligible because a significant amount of fundamental concepts presented were synthesized from other courses in the curriculum. SE 1 provided an introduction (roadmap) to concepts students would learn in future courses, while SE 103 synthesized topics learned in previous courses. Instead of classes in which lectures are primarily used to restate the textbook and students are taught procedures to solve a limited set of problem types, these two courses aim to get the students to understand and apply concepts to general problems and to develop the ability to think critically.

In the two case study courses, there was not a textbook, so some time was required to present mathematical derivations for new topics introduced. In core courses such as statics and dynamics, the instructor could eliminate a significant amount of mathematical derivations from lectures at the expense of relying on students to do the required outside reading. The authors appreciate that moving to a clicker-based PI framework will vary from instructor to instructor

and will require discretion the selection of topics that are relevant enough to remain in lecture (e.g., the core building blocks of the course) versus topics that could be learned from assigned reading. If applied correctly, the authors believe that, although requiring students to do more independent studying outside of class, the PI framework promotes discussion and clarification of common misconceptions about course topics, provides immediate instructor feedback, and promotes the ability to think critically and communicate engineering concepts.

5. References

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6. Appendices

6.1 End-Term Student Survey Questions

1. Select **all** statements which are true of you:
    A. I have used clickers before in a computer science class at this school.
    B. I have used clickers before in a physics class at this school.
    C. I have used clickers before in a biology or chemistry class at this school.
    D. I have used clickers before in a psychology class at this school.
    E. I have used clickers before in some other class at this school.
    F. I have used clickers at some other institution before.
2. If you have used clickers in another class at this school, tell us the instructor name (or, if you can't remember, the class number). **(Free Response)**

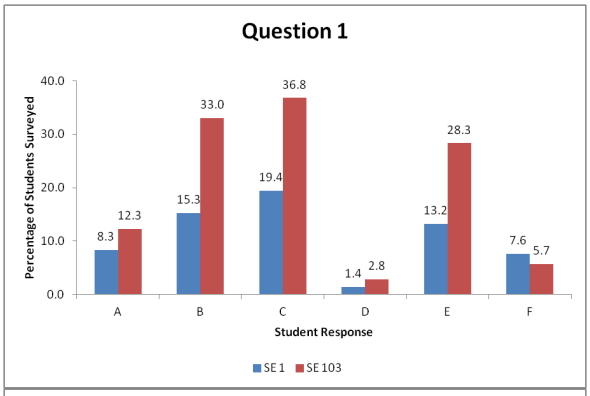
(3-18) For Questions 3-18, please rate your agreement with the following statements, using the response options below:
    A. Disagree very strongly
    B. Disagree strongly
    C. Disagree
    D. Agree
    E. Agree strongly
    F. Agree very strongly

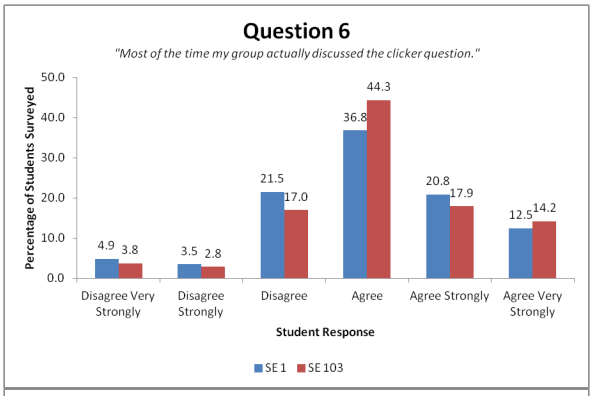
3. Thinking about clicker questions on my own, before discussing with people around me, helped me learn the course material.
4. Most of the time I actually read the required material before class
5. Pre-lecture reading quizzes helped me recognize what was difficult in the reading.
6. Most of the time my group actually discussed the clicker question.
7. Discussing course topics with my seatmates in class helped me better understand the course material.
8. The immediate feedback from clickers helped me focus on weaknesses in my understanding of the course material.
9. Knowing the right answer is the only important part of the clicker question.
10. Generally, by the time we finished with a question and discussion, I felt pretty clear about it.
11. Clickers are an easy-to-use class collaboration tool.
12. Clickers helped me pay attention in this course compared to traditional lectures.
13. Clickers with discussion are valuable for my learning.
14. I recommend that other instructors use this approach (reading quizzes, clickers, in-class discussion) in their courses.
15. Clickers in this course encouraged me to think critically about lecture material more than in a standard course.
16. My performance on reading quiz questions motivated me to review the material.
17. My performance on reading quiz questions motivated me to change study habits for future reading quizzes.
18. My performance on peer discussion questions motivated me to seek clarification on my misunderstandings of the material.
19. Comments? **(Free Response)**
20. From the point of helping me learn, the content of the clicker questions was:
    A. Much too hard
    B. Too hard
    C. OK
    D. Too easy
    E. Much too easy
21. In general, the instructor gave us enough time to read and understand the questions before the first vote.
    A. No, far too little time
    B. No, too little time
    C. OK amount of time
    D. Yes, too much time

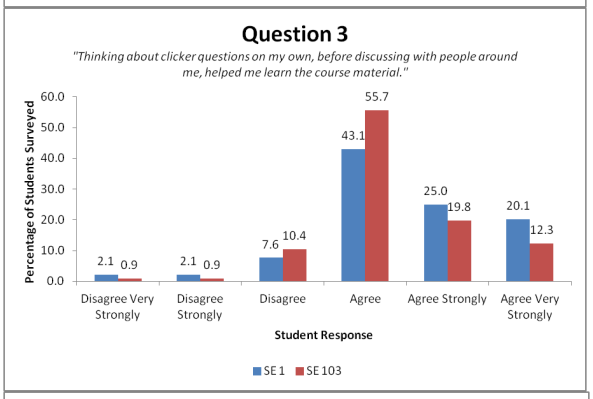
E. Yes, far too much time

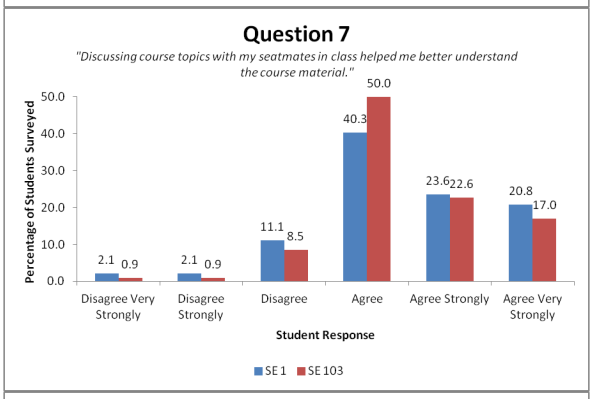
22. Which of the following best describes your discussion practices in the class this term?
    A. I always discuss with the group around me, it helps me learn
    B. I always discuss with the group around me, I don't really learn, but I stay awake
    C. I sometimes discuss, it depends
    D. I rarely discuss, I don't think I get a lot out of it
    E. I rarely discuss, I'm too shy
23. The amount of time generally allowed for peer discussion was:
    A. Much too short
    B. Too short
    C. About right
    D. Too long
    E. Much too long
24. In general, the time allowed for in-class discussion (after the group vote) was:
    A. Much too short
    B. Too short
    C. About right
    D. Too long
    E. Much too long
25. In general, it was helpful for the instructor to begin class-wide discussion by having students give an explanation.
    A. N/A – the instructor rarely did this
    B. It was not helpful to hear other students' explanations
    C. It was helpful to hear other students' explanations
26. The professor explained the value of using clickers in this class.
    A. Not at all
    B. Somewhat, but I was still unclear why we were doing it
    C. Yes, they explained it well
    D. Yes, they explained it too much
27. Compare and contrast your role as a student in *this* course's LECTURE with other "standard" course lectures. **(Free Response)**

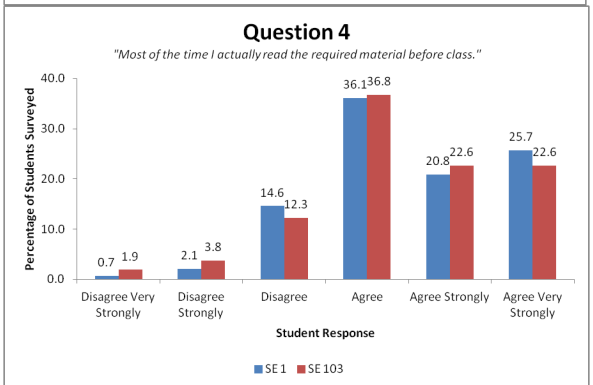
6.2 Student Response Histograms

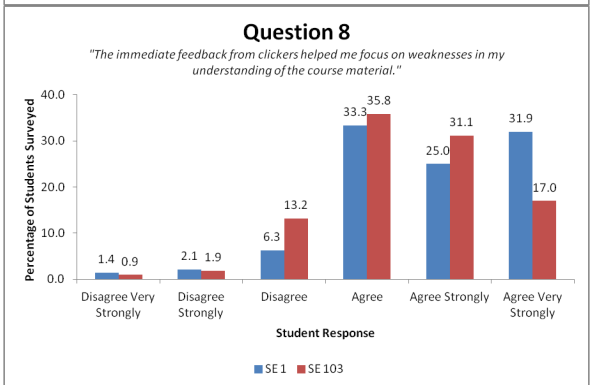


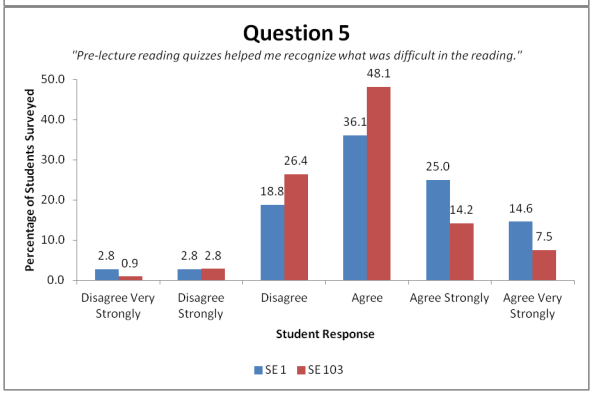


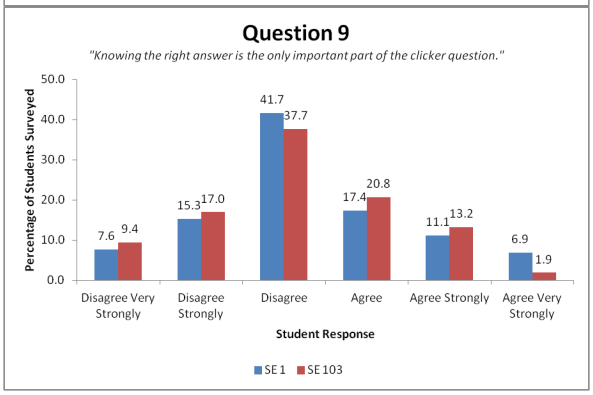






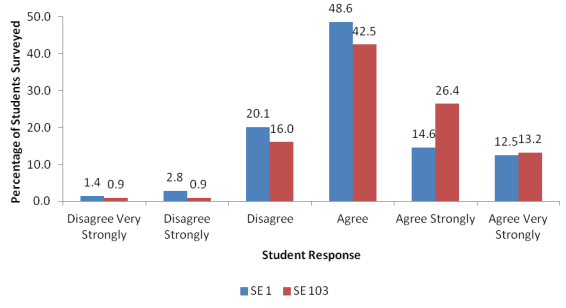






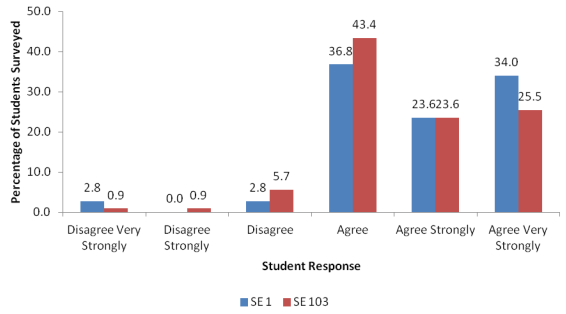
Question 10

"Generally, by the time we finished with a question and discussion, I felt pretty clear about it."



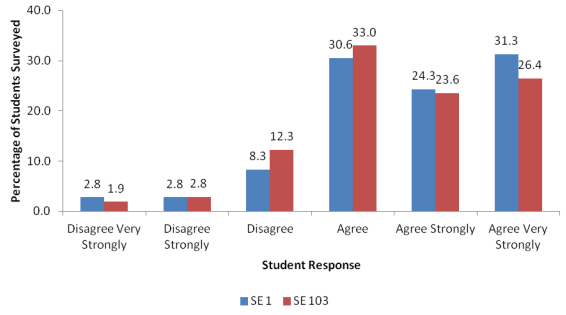
Question 11

"Clickers are an easy-to-use class collaboration tool."



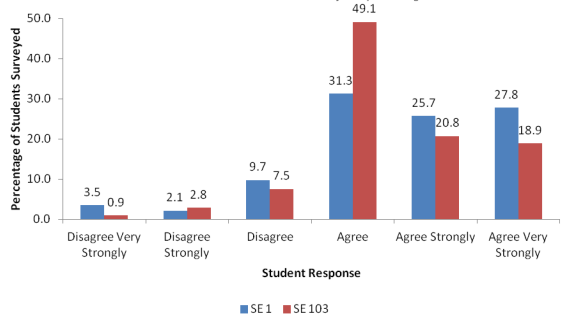
Question 12

"Clickers helped me pay attention in this course compared to traditional lectures."



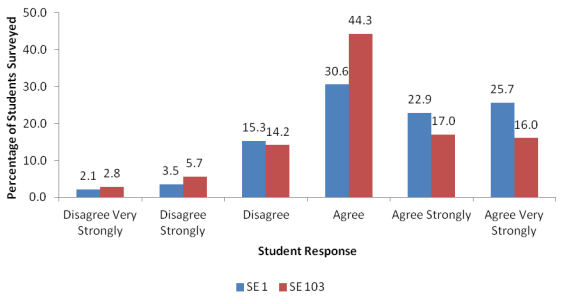
Question 13

"Clickers with discussion are valuable for my learning."



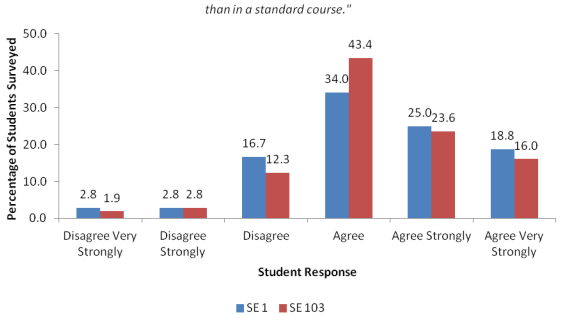
Question 14

"I recommend that other instructors use this approach (reading quizzes, clickers, in-class discussion) in their courses."



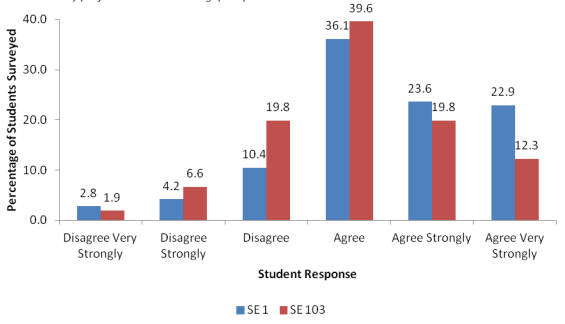
Question 15

"Clickers in this course encouraged me to think critically about lecture material more than in a standard course."



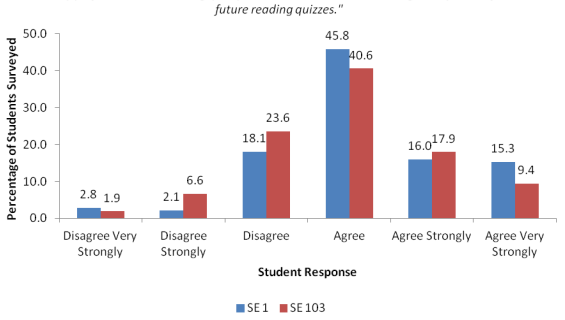
Question 16

"My performance on reading quiz questions motivated me to review the material."



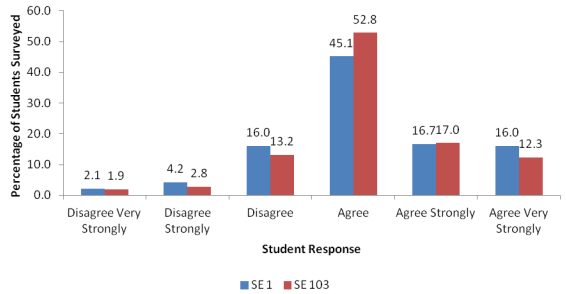
Question 17

"My performance on reading quiz questions motivated me to change study habits for future reading quizzes."



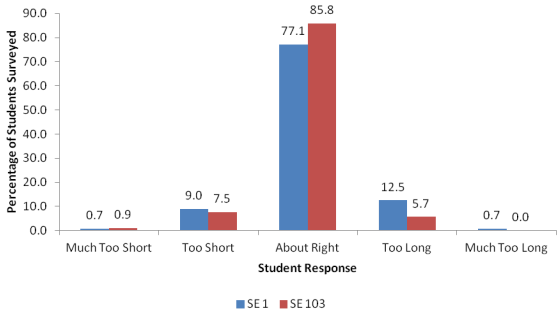
Question 18

"My performance on peer discussion questions motivated me to seek clarification on my misunderstandings of course material."



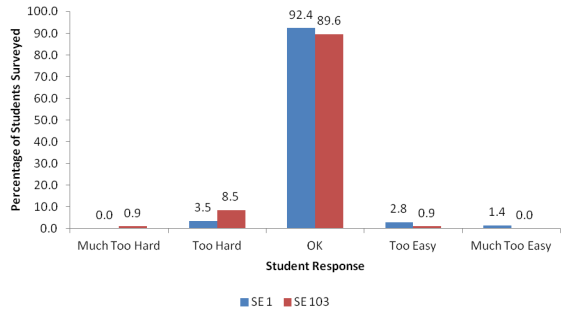
Question 23

"The amount of time generally allowed for peer discussion was:"



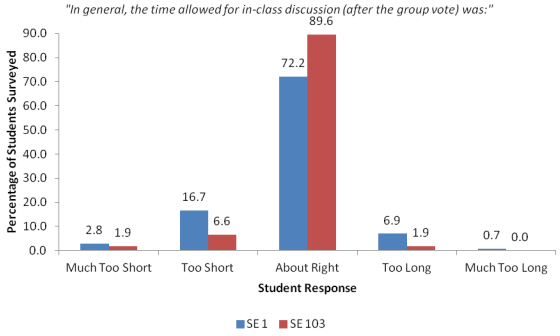
Question 20

"From the point of helping me learn, the content of clicker questions was:"



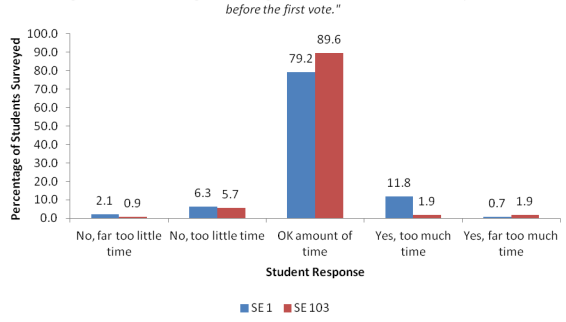
Question 24

"In general, the time allowed for in-class discussion (after the group vote) was:"



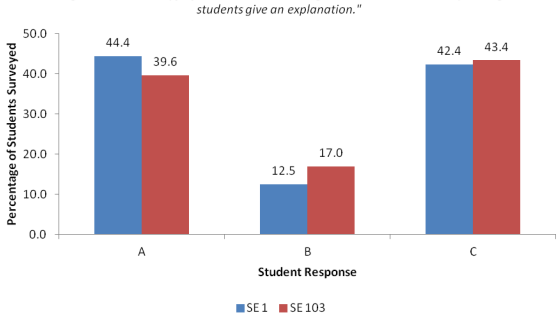
Question 21

"In general, the instructor gave us enough time to read and understand the questions before the first vote."



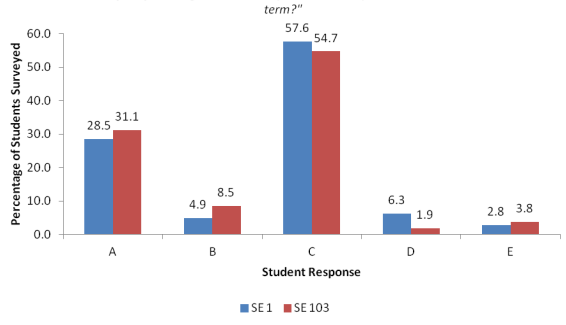
Question 25

"In general, it was helpful for the instructor to begin class-wide discussion by having students give an explanation."



Question 22

"Which of the following best describes your discussion practices in the class this term?"



Question 26

"The professor explained the value of using clickers in this class."