Clickers Beyond the First-Year Science Classroom

By Marina Milner-Bolotin, Tetyana Antimirova, and Anna Petrov

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This case study's primary objective is to describe the implementation of the electronic response system (clickers) in a small (N = 25) second-year physics course at a large public university and to draw attention of the science faculty who teach upper-level science courses to the potential benefits of this pedagogy. This pilot study discusses the impact of the clicker-enhanced pedagogy on students' cognitive and affective outcomes and their attitudes toward using clickers. We also outline challenges faced by the students and the instructors on the way of successful clicker implementation beyond the first year and suggest a few possible ways of addressing them.

During the past decade, the use of electronic response systems or classroom performance systems (clickers) became widespread in undergraduate programs, both science and nonscience alike (Duncan 2005; Lasry 2008; Milner-Bolotin 2004; Mayer et al. 2009; Keller et al. 2007; Hoffman and Goodwin 2006). "Clicker technology" consists of a radio-frequency receiver, individual student clickers, and the supporting software for the analysis of student responses (*www.einstruction.com*).

There are many reasons why science instructors are so eager to incorporate clickers. First of all, during the past 30 years, physics educators developed reliable and easy-to-administer concept surveys that allowed assessment of student learning (Thornton and Sokoloff 1998; Perkins et al. 2004; Hestenes, Wells, and Swackhamer 1992) and made the comparison of the learning gains across various educational institutions possible (Hake 1998). These instruments allowed objective measurement of student learning in terms of their cognitive and affective outcomes (Mazur 1997a, 1997b). Consequently, a number of instructors became conscious that traditional teacher-centered approaches have limited effectiveness in science classes, especially considering the changing student demographics, increased class sizes, and a renewed emphasis on developing critical-thinking skills (Mazur 2009).

Furthermore, science educators have made considerable progress in identifying student conceptual difficulties and designing teaching methods to address them (Arons 1997; Kalman 2008; Kalman 2006). The majority of these strategies incorporate active learning and student-centered learning environments (Hake 1998), encouraging student–student and student–instructor interactions. Many of the science instructors who wish to promote active learning use clicker pedagogy. A quick online search using "clicker science education" keywords yielded more than 849,000 links, including more than 440 related books and book chapters. Finally, science educators produced an extensive volume of research-based materials that help instructors to get started in using interactive teaching methods. For example, many of the science book publishers include clicker questions in the textbook packages, so new instructors can start by incorporating ready-to-use questions. In addition, there is a growing number of online databases dedicated to sharing effective clicker questions among the instructors (Harrison 2005; Mazur 1997b). However, although the effects of clicker-enhanced pedagogies in large introductory science courses have been studied extensively, little has been done to investigate clicker potential beyond the freshman year. The goals of the study are (a) to demonstrate that clicker-enhanced pedagogy can be implemented effectively in a small (*N* = 25) upper-level physics course at a large public university; (b) to collect student and instructor feedback on effective clicker use in upper-level courses; and (c) to identify potential benefits of clicker-enhanced pedagogy beyond the first year, as well as instructional challenges and the ways of addressing them.

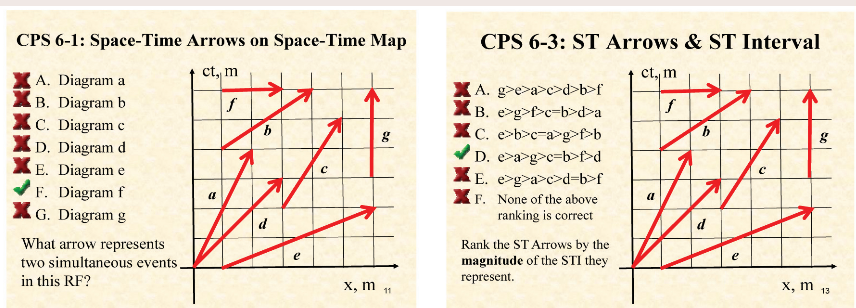
Clicker implementation in a second-year physics course

In large universities, upper-level physics courses are usually significantly smaller than introductory physics courses: tens versus hundreds of students. Upper-level physics courses are designed specifically for physics or chemistry majors, with the goal of solidifying student knowledge gained in the first year and introducing students to the more advanced fields of physics. These courses are cognitively more demanding, as they often require putting together multiple concepts and applying them to novel situations. In addition, upper-level science courses require a higher level of abstraction, attention to technical details, and rigorous mathematical treatment. As a result, the conceptual side of the topic is often neglected, focusing mostly on mathematical representations of physics problems. For the instructor, despite the small class size, teaching a second-year physics course poses a challenge as this is often the first "real" university-level physics course experienced by the students that is aimed at developing higher-order critical-thinking skills in a physics context (Bloom 1956).

The Modern Physics course described in this study fits perfectly within this description. The course was designed for the second-year medical physics students ($N = 25$) and covered the topics of special relativity and introduction to quantum mechanics. It included four hours of classes a week and was taught by an instructor with the help of a teaching assistant. Because of the small class size and the availability of the Hewlett-Packard tablet computers (Milner-Bolotin, Antimirova, and Zambito 2008), the instructor had the flexibility to use computer simulations and online resources during the class. The students in this course have all previously used clickers (*www.einstruction.com*) in their first-year physics and chemistry courses and therefore not only owned clickers, but were already familiar with the technology. Clickers were used on a daily basis with few rare exceptions because of technical difficulties. On average, four clicker questions were asked per class, and although most of them were multiple-choice questions dedicated to the course material (see Figure 1), a few were survey questions asking for student anonymous course feedback. From the very beginning, the students were informed that 5% of their final mark would be based on their clicker participation: For every correctly answered question they earned two points, for every incorrect attempt, they earned one point.

FIGURE 1

Examples of two multiple-choice clicker questions asking the students to interpret the space-time (ST) arrows on a space-time diagram. Question CPS 6-1 is a lower-level question that probes student understanding of the concept of a ST arrow. Question CPS 6-3 is a more advanced question that requires the students to connect the concepts of a ST arrow and a space-time interval. CPS = Classroom Performance System; RF = reference frame; ST = space-time; STI = space-time interval.



The procedure for the administration of clicker questions is displayed in Figure 2. We call it a modified peer instruction (MPI) because it is based on the original peer instruction method proposed by Mazur (1997b). MPI method can be split into the following main stages:

1. The instructor poses a clicker question on the board (e.g., Figure 1).
2. The students are given a limited amount of time to think of the answer and submit it using clickers. At this stage student collaboration is not allowed.
3. The summary of student responses is displayed without revealing the correct answer.
4. Two possible outcomes follow: either most of the students answered the question correctly and only a brief summary is needed to clarify the answer to the few who answered incorrectly, or the majority answered incorrectly and thus the question revealed difficulties in student conceptual understanding.
5. In the latter case (in #4), the instructor asks the students to discuss the question with their peers and vote again.
6. The revote is followed by a group discussion and detailed explanation of the reasons behind the correct, as well as the incorrect, responses to ensure that the students had a chance to construct a deep conceptual understanding.

Commonly, after the students vote for the second time, a statistically significant number of students select the correct response. We would like to think that this indicates an improvement in student understanding, which future studies may be inclined to address (Smith et al. 2009; Lasry, Mazur, and Watkins 2008; Mazur 1997b). Moreover, during the peer discussion stage, the instructor circulates among the students, asks leading questions, notices student difficulties, and helps the students to clarify the concept. If a question is particularly interesting, the instructor uses student responses as a basis for the further discussion and clarification of the concept. It is worth mentioning that when the students revote, their initial responses are overwritten. This way the majority of the students have reasonably high clicker participation marks, which are perceived by the students as formative, rather than the summative assessment that contributes to their positive course performance.

Results

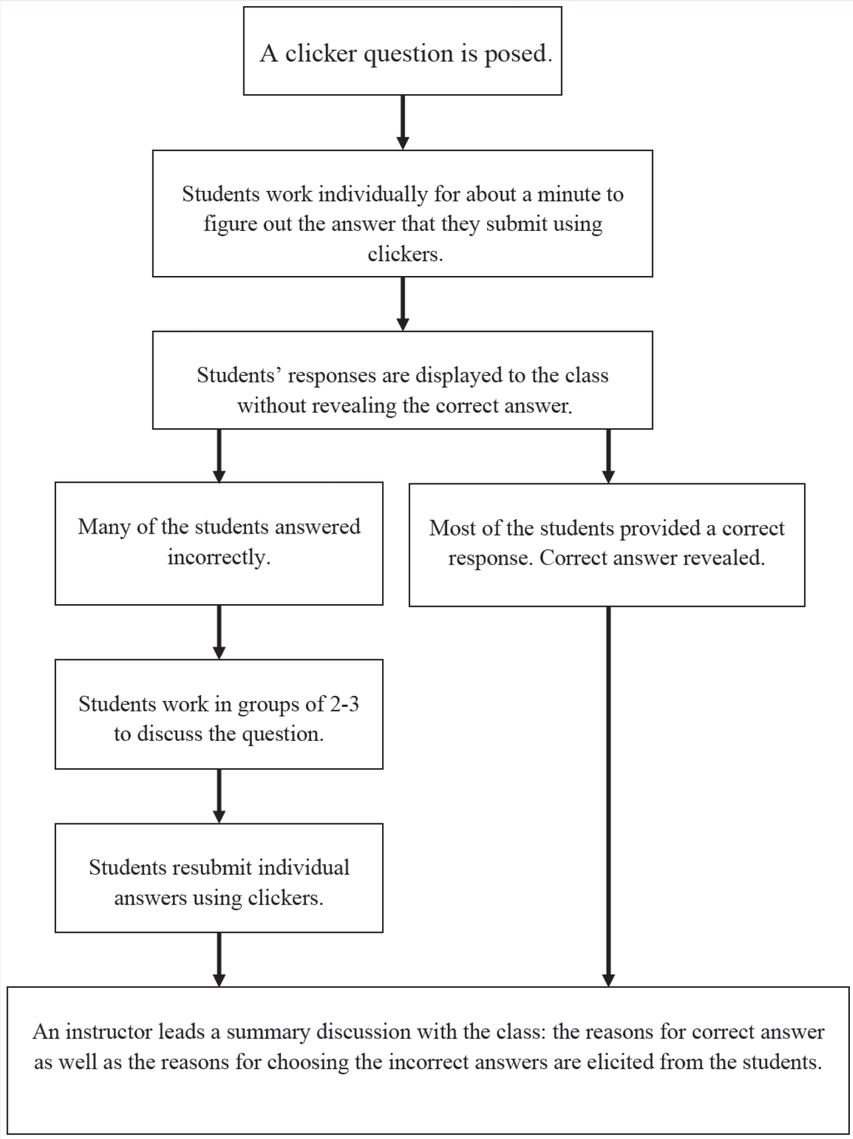
To assess students' attitudes toward clickers and their perception of clicker effectiveness, the researchers used an anonymous course survey. Clicker effectiveness was defined as student perception of how much clicker pedagogy helped them stay engaged in class, understand the material, get continuous formative feedback on their progress, clarify difficult concepts, and reflect on their own learning. One of the questions on the survey specifically asked student opinion about the usefulness of clickers: "Would you recommend using clickers beyond the first-year courses?" Out of 17 respondents, 12 students (70%) said that they would recommend the use of clickers because they find them helpful, 3 students (18%) said that they were neutral, and 2 students (12%) said that the clickers were a waste of time and they would not recommend them. In order to clarify students' answers to the survey (e.g., to make sure their interpretation of "clicker effectiveness" coincides with the one of the researchers) and to solicit additional reasons for student choices, the researchers conducted semi-open interviews with student volunteers. The interviews were administered by the research assistant, and the results were not revealed to the course instructor until the course was over. During the interviews, the students were asked to reflect on different technology uses in their science classes as well as on the effectiveness of clickers. Here are some of the excerpts from these interviews:

Student 1: "Use of technology makes the lectures fun, like the use of clickers. It is a motivation to attend the class, discuss the topic, and get feedback."
Student 2: "Use clickers for every class: the more the better."
Student 3: "Yes, use clickers in every single class."
Student 4: "Clickers should be used beyond the first year because they help to prepare for midterms, provide feedback for the teacher and the students, are interactive, and provide an easy way for the students to get good marks."
Student 5: "The clickers are easy and convenient to use."
Student 6: "Clicker technology is a tool to learn more and to understand the concepts."

Only 2 out of 10 interviewed students mentioned that the clickers are ineffective in small classes compared with large ones. One out of the 10 interviewed students stated that clickers are not necessary in upper-level

FIGURE 2

A flow chart representing modified peer instruction pedagogy.



physics courses, whereas 9 out of 10 students responded that they would recommend the use of clickers beyond the first year. During the interview, students were prompted to reflect on what they like and dislike about the use of clickers in the upper-level science classes. Their responses are summarized in Table 1.

In summary, the majority of students found clickers to be helpful for learning physics beyond the first year. They were positive about active class participation and the dynamic learning environment. Many of them enjoyed using clickers in their freshman science courses; therefore, using clickers in the second year was a natural extension. It is not surprising that the main advantage of using clickers, from students' perspective, is an immediate feedback and an opportunity to clarify physics concepts. The biggest complaint about the use of clickers was the fact that class attendance was rewarded, such that students who would skip the class otherwise were "forced" to attend it. However, the class participation mark based on the clicker input (5% of the total grade) did not lower the grade for any one of the students; rather, it improved each student's final mark. It is important to mention that despite its proven effectiveness, active class participation via group problem solving and in-class discussions (Smith et al. 2009) often clashes with students' expectations that the most effective mode of learning is reading the textbook or following the lecture notes posted online, which can be done at home. This might explain why not all of students liked the clicker-enhanced instruction.

From the instructor's perspective, the use of clickers provided necessary feedback on students' progress and helped the instructor to focus on difficult concepts via facilitating meaningful student–student and student–instructor interactions. There is an additional benefit of using clickers versus using other student-centered pedagogies. Student responses to clicker questions can be easily recorded. As a result, this information becomes live educational data on student learning that can be analyzed by the instructor outside of class. It can reveal student conceptual difficulties, common mistakes, and misconceptions, as well as help the instructor gauge the quality of student learning and consequently the quality of her own teaching. Clicker technology is an invaluable tool for reflective instructors who are interested in examining their own teaching practices.

Although the limitations of the current study (the lack of a control group and a small number of participants) did not allow us to single out the effect of a clicker-based pedagogy on student academic achievement, the fact that both the students and the instructors have positive attitudes toward clicker-enhanced instruction makes the further investigation of the effect of this pedagogy on student academic achievement worthwhile.

Addressing the challenges

There are several reasons why science instructors are still reluctant to use clickers beyond the freshman year. First of all, there is still a prevalent view among them that the main goal of the upper-level courses is to "cover the material," and using clickers or any other interactive engagement methods reduces the amount of time available for direct lecturing. As more research evidence is collected supporting the claim that the effectiveness of the interactive engagement methods reaches beyond the first year, science educators will be able to use it to convince science instructors to use interactive engagement in upper-level courses. Another reason is the fact that creating effective clicker questions is challenging and time consuming (Beatty et al. 2006). Regarding the introductory courses, science education researchers have made significant progress in understanding student difficulties and creating appropriate teaching methods, including effective clicker questions. This situation is

TABLE 1

Summary of student opinions about the use of clickers in the second-year Modern Physics course.

What the students liked about the use of clickers (number of respondents out of 10)		What the students disliked about the use of clickers (number of respondents out of 10)	
Immediate feedback from the teacher	7	Losing marks for missing classes (attendance/participation)	5
Practice for midterms	2	Technical problems with technology	3
Interactivity (not just reading or writing but engaging)	3	Clickers discourage you if you got a wrong answer	1
Reinforcing student attendance by giving marks for participation	4	Clicker questions are too fast, not enough time to think of the answer	1
Direct simple conceptual problems are helpful	1	Clickers take away time from the lecture	1

currently not applicable for the upper-level courses. The work in this area had just began, and thus the instructors who are determined to use clickers in upper-level courses will be required to design a significant number of these questions themselves. This will require a few iterations and will be best accomplished when science educators work on it as a community. Moreover, in order to evaluate the effectiveness of interactive engagement methods such as clicker-enhanced pedagogy, a more uniform learning assessment tool specific to upper-level courses should be constructed. Only when science educators designed reliable instruments, such as Force Concept Inventory, Force and Motion Conceptual Evaluation (Thornton and Sokoloff 1998; Hestenes, Wells, and Swackhamer 1992), to measure student learning in introductory physics courses, it became clear that traditional teaching methods were ineffective for the majority of the students. It can be predicted that the same will happen when similar instruments for upper-level science courses become available and widely used.

We are convinced that clicker-enhanced pedagogy has a potential to become an effective educational tool that will help science instructors in facilitating meaningful science learning beyond the first year. We invite the instructors who want to use clickers in upper-level courses to combine efforts in designing effective clicker questions, sharing their experiences and creating a community of practice aimed at promoting interactive engagement in science courses at all levels. We welcome e-mails from the interested instructors in science, mathematics, and engineering disciplines. ■

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Marina Milner-Bolotin (marina.milner-bolotin@ubc.ca) *is an assistant professor in the Department of Curriculum and Pedagogy, Faculty of Education, at the University of British Columbia in Vancouver, Canada.* ***Tetyana Antimirova*** *is an associate professor in the Department of Physics at Ryerson University, Toronto, Canada.* ***Anna Petrov*** *is a graduate of the Department of Chemistry and Biology at Ryerson University in Toronto, Canada.*