

Examining the Effectiveness of Clickers on Promoting Learning by Tracking the Evolution of Student Responses

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Abstract. Personal Response Systems or clickers have been used for a number of years to help create active learning environments in the lecture classroom. Researchers have shown that the use of clickers stimulate student-student and student-lecturer interaction. In addition, students value the use of clickers and feel that these devices contribute to their understanding. Even though clickers have been used for quite some time, there are relatively few research studies focusing on how student knowledge is enhanced through the use of clickers. To contribute to this body of research, we compared student responses on exam questions to similar or identical clicker questions that were presented during lecture. The analysis of the responses to both clicker and exam questions show how individual student knowledge evolves during instruction. Although there is evidence of improvement during lecture, many students were unable to respond correctly when the questions were posed on the exam, despite the similarity in the questions.

Keywords: Clicker questions, Personal Response Systems, Physics Education Research

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INTRODUCTION

In the last four years, the physics program at Chicago State University (CSU) has made major revisions to its introductory physics courses. These changes began with the implementation of research-based laboratories developed by Kanim, Loverude, and Gomez.¹ Soon after the laboratories were introduced into the introductory physics classes, CSU began a large-scale overhaul of the introductory physics sequence, which included modifications to the problem-solving sessions and the lecture portions of the course. CSU is now incorporating each of these reformed components into a coherent unit where students move back and forth between the lecture, laboratory, problem-solving and discussion. The most recent modification to the course is the addition of Clicker Question Sequences (CQSs). CQSs have been used in the calculus-based courses at CSU and give students the ability to vote without their peers knowing how they voted on questions posed by the instructor. Instructors are able to get immediate feedback as to where the class is in their understanding of different topics [1].

The implementation of the question sequences and the research on the effectiveness of these materials are part of a National Science Foundation – Course,

Curriculum, and Laboratory Improvement (CCLI) grant led by the Ohio State University. CSU, the College of DuPage, and Wright College are pilot sites for the project, each with very different populations of students. The idea behind question sequences comes from work done by the Ohio State University where they found that two types of sequences were effective in promoting understanding [2,3]. These sequences include “rapid fire,” questions at a similar difficulty level that can be done rather quickly, and “easy-hard-hard,” in which the first question helps build student confidence and helps them identify relevant concepts, and the remaining two questions require a significant degree of transfer.

Although many researchers have found that the effective use of peer instruction techniques and the use of clickers can help create a dynamic learning environment in the lecture class by fostering peer interaction and accountability, there are only a few studies documenting the effect clickers have in promoting better understanding of the content in the physics course [4,5].

In order to contribute to this body of research, the physics program at CSU is involved in an ongoing project in which targeted studies are conducted to assess the effectiveness of the CQSs in helping students construct understanding. We contrast this study with more broad studies that use the analysis of pre and post scores on diagnostics carried out using

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control groups. Although these studies are often very useful, they assess the entire instructional approach, including: clickers, lectures, laboratories, and problem solving. It is often difficult to attribute gains to a single course component, even though researchers may be careful to control all other variables.

In this study we focus our assessment on the use of clickers by taking CQs from the lecture and posing either identical or similar questions on student exams. These questions were posed in a single class, allowing us to track individuals as they progressed through the course. The analysis of the responses to both clicker and exam questions shows how individual student knowledge evolves during instruction.

In addition to analysis of clicker question responses and written responses on exams, we have also conducted interviews with student volunteers regarding responses to the questions in this study. Because of space limitations, and the complexity of responses, we do not describe the interview results in this paper.

One advantage of using question sequences, rather than single questions, is that we are able to gain more understanding of the evolution of student knowledge. By looking at responses on the sequences and then comparing these responses to those on an exam question, we can analyze changes in the short term (individual questions in a sequence) and the long term (question sequences and exam).

In this study we present examples from two contexts: kinematics and vectors. All students involved in the study were STEM majors enrolled in the calculus-based Physics I course at CSU. (This is the first part of a three semester sequence.) Sabella was the instructor for the course.

KINEMATICS

During our physics courses we often attempt to help students bridge between multiple representations [6]. We believe that this helps students connect knowledge that is often fragmented [7]. CQs provide an excellent opportunity for students to make this connection due to the quick succession of questions. The first set of questions we discuss focuses student attention on both the algebraic and the graphical representations used in the study of kinematics.

Fig. 1 shows the question sequence given during lecture. Students first responded on their own, using the clickers. They were then shown the distribution of responses to the question. Because of the spread of answers on each of the clicker questions in this sequence, the instructor asked the students to discuss the questions after the initial vote and then revote.

We will focus on the first question in the sequence and describe how student responses evolved. On the first attempt at question 1 we found that 5 of the 16 (31%) students selected the correct answer for the equation that correctly describes the motion: $3^m/s t - 1m$. The most common incorrect response was $1m t + 3^m/s$, given by 5 of the 16 (31%) students. After students were given the opportunity to discuss the question, many changed their responses and the class as a whole began to move toward the correct answer. On the 2nd attempt, after discussion with peers, 9 (56%) students answered correctly.

Although this may suggest class improvement and imply conceptual change, there are a number of possible reasons for the class shift toward correct. Students who initially answered incorrectly could have changed their minds after discussion, or they could have simply adopted the ideas of their peers without developing an understanding.

On exam 1 we asked an almost identical question to question 1, also in multiple-choice format. The only difference between the clicker question and the exam question was the addition of a “none of the above” choice. Our hope was that because we did see some improvement on this question during the clicker-sequence, and because students were engaged in student-student dialogue as well as student-instructor dialogue, we would see fairly good performance when this question was posed on an exam. We found that when posed on the exam, only 4 of 12 (33%) students

Q1. An object starts $1m$ to the left of the origin and travels to the right with a constant speed of $3m/s$. Use a coordinate system in which the positive direction is to the right. Choose the equation that describes the position of the object as a function of time.

Q2. An object starts $1m$ to the left of the origin and travels to the right at a constant speed covering 4 meters in 20 seconds. The coordinate system is shown at right. Choose the equation that describes the position of the object as a function of time.

Choices for questions 1 and 2 are a set of possible equations that would describe this motion.

Q3. An object starts $1m$ to the left of the origin and travels to the right at a constant speed. The coordinate system is shown at right. Choose the graph that describes the position of the object as a function of time.

Choices for question 3 are a set of possible graphs that would describe this motion.

FIGURE 1: Kinematics Clicker Question Sequence used in lecture.

answered correctly, despite the similarity in questions. Fig. 2 shows how students responded to the question when asked as a clicker question and as an exam question and shows how the responses evolved, with thicker lines indicating more students. Darkly shaded response choices in the figure indicate correct answers. Despite the fact that the majority of the class moved toward the correct response on the 2nd attempt, responses diverged from the correct response on the exam. Four students who responded to the clickers during class were unable to take the exam.

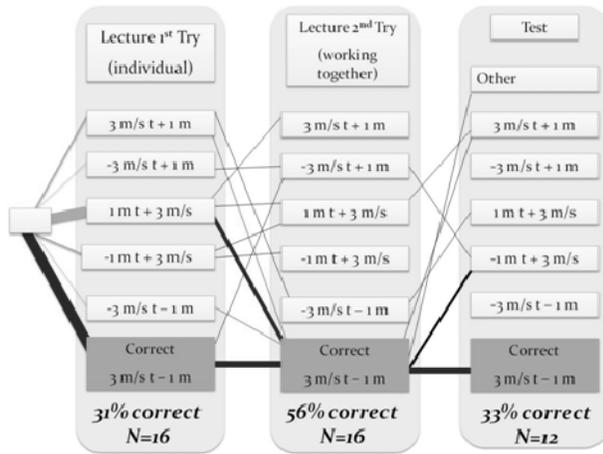


FIGURE 2: The evolution of student responses on the kinematics questions.

VECTORS

The second example deals with the addition and subtraction of vectors in two dimensions. This CQS involved three questions that are increasingly difficult.

Students were given two vectors, **A** and **B**, and were asked to determine the following resultant vectors: **A** + **B**, **A** - **B**, and 2**A** - **B**. Fig. 3 shows vectors **A** and **B** as well as the questions from all three clicker questions in the sequence and the exam question. Solutions are provided in the figure as well.

Students performed better on the vector questions than on the kinematics questions posed earlier. On the first clicker question (**A** + **B**), 11 of the 16 students (69%) answered correctly. Because most of the class answered correctly, students were not given a second opportunity to vote. The instructor led a discussion where the class simply discussed which answer was correct and why. It was encouraging that when the second, harder question, was asked, 13 students (81%) answered correctly. This suggests that students were improving on this type of question even though students were not given second attempts and, in each of these cases, students worked individually. On the final question (2**A** - **B**), the hardest question of the

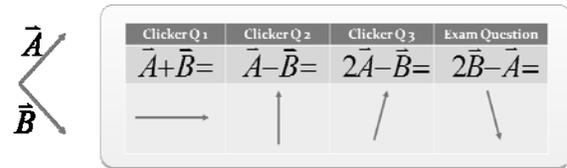


FIGURE 3: Two-dimensional vector question sequence.

three, students showed further improvement, with 15 students (94%) answering correctly, again suggesting that this clicker sequence was helping students develop a stronger understanding of vector addition and subtraction. The class showed an increased level of confidence and even expressed surprise when a single student answered incorrectly on the last question in the sequence.

The question was then posed on the exam, again in multiple-choice format. The only difference was that on the exam, students were asked to determine 2**B** - **A** (rather than 2**A** - **B**). On the exam, only 5 of 12 students (42%) answered correctly. One explanation for this is that, during lecture, students had a sequence of questions before the final question which may have primed them to answer a certain way. An exam question consisting of a sequence, rather than a single question, can help us answer this question in future work. Figure 4 shows the evolution of responses on these questions.

This result was quite surprising based on the performance and improvement observed during the lecture when the students were engaged in the clicker sequence. It is also interesting to note that students

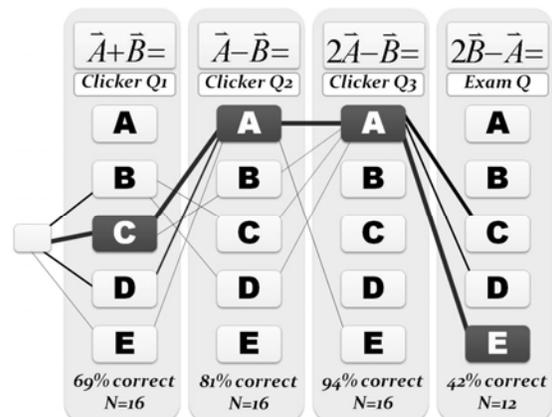


FIGURE 4: The evolution of student responses on the vector questions.

were not simply recalling what they had done in the class. The most common response was a response consistent with the vector **A** + **B**, not 2**A** - **B** or 2**B** - **A**. One possible explanation for this is that on an exam, students engage in a different response mode. They see the two vectors and quickly add them, not

considering what the question is asking. In previous work, we have described this as students activating an intuitive set of knowledge, rather than a formal knowledge (knowledge built up in the course) [8].

SUMMARY

In both these examples, students appear to be building up formal physics knowledge during class time. The evidence for this is the improvement in performance during in-class work. In the first case, we looked at a single question in the sequence and saw that after peer discussion more students were able to answer correctly. Although this is one of the useful components to peer instruction, the fact that student understanding improved after discussion can be debated. One criticism is that students who initially answered incorrectly simply adopted the ideas of the high performing students – students who do well on exams and homework. Results on the exam suggest that this may be the case. But in the second example, involving 2-D vectors, students were answering as individuals, so the fact that students were improving during the CQs on questions that increased in difficulty is much more suggestive of improvements in understanding. It is interesting that despite these improvements in-class (94% of the students answering correctly on the final clicker question), students did not perform well on the corresponding exam question.

These results, as well as results from previous work, suggest that the poor performance on exams is not simply a result of lack of content knowledge. In this case, and in previous work we have provided evidence that student content knowledge does exist – students are able to access the knowledge and are able to apply the knowledge correctly – triggering the knowledge in certain contexts is difficult (See ref. 8.). In this study this is demonstrated by the performance on the 2-D vector questions during lecture. These studies suggest that an explanation for our results goes well beyond simply content knowledge - it is much more complex.

The CSU Physics Program is at a point where we feel that continued revising of instructional materials will not yield better student performance. Instead, we must consider the metacognitive and test-taking skills that our students possess. Specifically,

- what skills do we need to train our student to use so that they are able to capitalize on the learning gains from class to perform well on exams and diagnostics?
- how can we help our students trigger the formal physics knowledge they are developing when it is required?

Although these are important questions, we understand that these issues should not dictate what we do in the classroom. But, if we want to assess our students' formal physics knowledge, we need to have something to assess. This requires that students access the formal knowledge and utilize the formal knowledge; only then can we assess it. In many of our investigations, students are not bringing the formal knowledge to the task and we are simply assessing the quick, intuitive knowledge they often use on exams and diagnostics. What is often discouraging is that many faculty and assessment bodies typically focus on the results from diagnostic and exam results and therefore miss much of the student growth – growth that is often difficult to describe and evaluate.

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