A Clicker Approach to Teaching Calculus

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Clickers (electronic voting systems) are all the buzz in higher education these days as many universities and colleges invest significant sums of money to integrate these systems into their classrooms. But what are clickers? Are they just another high-tech gimmick, or can they really be used to improve learning? Can clickers be used efficiently in calculus classes?

In an ideal world, students would take calculus for the sheer love of it. The reality is, however, that calculus is a service course, and most students take it to fulfill university requirements. Engaging students in calculus classes thus can be a challenge. Furthermore, in traditional lectures, students passively take notes, at times barely processing the material as they struggle to keep their attention focused for an hour. Students often fear that they are alone in not understanding the material and are at times afraid of asking questions in class. At the end of class, both students and instructor may leave without knowing whether the material has been understood.

Clickers can be used to address these challenges. The term "clickers" refers to the student input devices (see Figure 1) of electronic voting systems. These systems allow for two-way communication (generally radio frequency) between an instructor and a group of students. In classrooms with clickers, instructors can pose questions during class, usually on a PowerPoint slide, and the students respond anonymously using the keypad on their clickers. Responses to the question can then be displayed on a screen so both students and the instructor can see the percentage of the class that chose each response. Questions can range from multiple-choice, true/false, matching items, and ranking items, to numerical and short text answers. Clickers can be used in a variety of ways, from checking conceptual understanding, testing skills, provoking discussion, all the way to teaching and motivating new material. The benefits are manyfold:

Figure 1. Clicker device.

(1) Instructors receive instant feedback on the students' comprehension and misconceptions.
(2) Students receive instant feedback regarding their understanding and how they compare to the rest of the class.
(3) Students are more focused and are actively engaged in learning during class time.

To encourage peer-to-peer interactions, a clicker can be assigned to a group of students who must discuss their answer before responding to the question. In our experience, the small group setting provides a more intimate and non-threatening environment for students to admit difficulties with

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the material. Students are also more willing to divulge their answers in class since they are representing the group's work rather than the work of just one individual.

How can clickers be used in calculus classes to enhance learning? What type of questions are good clicker questions? First of all, clicker questions can be used in different contexts; before, during, or after introducing new concepts. The sample questions below are simple, basic questions with the goal of engaging students in discussion and learning. In parentheses are the percentages of students at Northwestern University in single variable calculus classes, 2006-07, who chose each response. All questions were asked *prior* to introducing or reviewing the concepts required to answer these questions. Students discussed their answers in small groups of two to six students *before* responding with the clickers.

Example 1. A discussion starter

True or False? $\arcsin(\sin \pi) = \pi$
(True 50%, False 50%)

Example 2. A misconception check

True or False? If f has a local maximum or minimum at $x = c$, then $f'(c) = 0$.
(True 89%, False 11 %)

Example 3. A basic concept check question

Suppose you know that a differentiable function f has $f'(3) = 0$, and $f''(3) = 4$. Which of the following statements must be true?

(a) *f has a local maximum at $x = 3$ (16%)*
(b) *f has a local minimum at $x = 3$ (32%)*
(c) *f has a point of inflection at $x = 3$ (42%)*
(d) *None of the above (10%)*

The purpose of this question was to help students discover the second derivative test on their own.

Example 4. A series of true/false questions

(1) *If $\lim_{n\to\infty} a_n = 0$, does that imply that $\sum_{n=a}^{\infty} a_n$ converges?*
(2) *Conversely if $\sum_{n=a}^{\infty} a_n$ converges, does that imply that $\lim_{n\to\infty} a_n = 0$?*
(3) *If $\sum_{n=a}^{\infty} a_n$ diverges, does that imply that $\lim_{n\to\infty} a_n \neq 0$?*
(4) *If $\lim_{n\to\infty} a_n \neq 0$, does that imply that $\sum_{n=a}^{\infty} a_n$ diverges?*

These questions were posed with the intent to lead students to discovery of the divergence test. While only 49% chose the correct answer for (1), by the time question (4) was posed, 81% chose the correct answer.

Example 5. A multi-step problem

A baseball diamond is a square with sides of 90 ft. A batter hits the ball and runs towards first base with a speed of 18 ft/s. At what rate is the distance from second base decreasing when he is halfway to first base?

Although this is a great standard calculus textbook problem ([1]) to ask on a quiz or test, this problem might be too complex to ask in the middle of class using clickers. However, a problem of this type can be divided into several parts as follows.

(i) Students are asked to draw a picture modeling the situation. With their clickers students indicate:
 (a) done drawing the picture
 (b) more time needed

 Students click when they have completed the task, and in their groups, select a student to put the picture on the classroom board.

(ii) The next PowerPoint slide includes a picture modeling the situation where x is the distance from the runner to first base, and z the distance from the runner to second base. Then students are asked what quantity this question is asking to find:

 (a) $x'(t)$, (b) $z'(t)$, (c) None of the above, (d) I don't know

(iii) The last part of this problem can then be posed as a multiple choice question to evaluate $z'(t)$, or, with more advanced clickers, students can enter the correct quantity for $z'(t)$.

All textbooks have great questions that can be modified to use with clickers. Some books, in addition, contain conceptual questions specifically designed to use with clickers, for example ConcepTests ([2], [3], [4]).

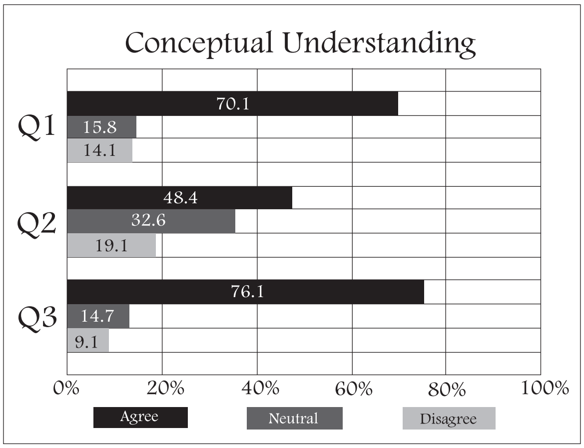
What do students think about clickers, and what is the evidence for better learning in classrooms with clickers? The following tables present survey data from 348 students in six different calculus classes taught by the same instructor at Northwestern University, 2005–2008.

Conceptual Understanding

[Q1] I am more aware of my misunderstandings/difficulties than in traditional classes.

[Q2] Using the clickers helps me to understand the concepts behind problems.

[Q3] The questions asked during clicker sessions help me to understand what is expected from me in this class.



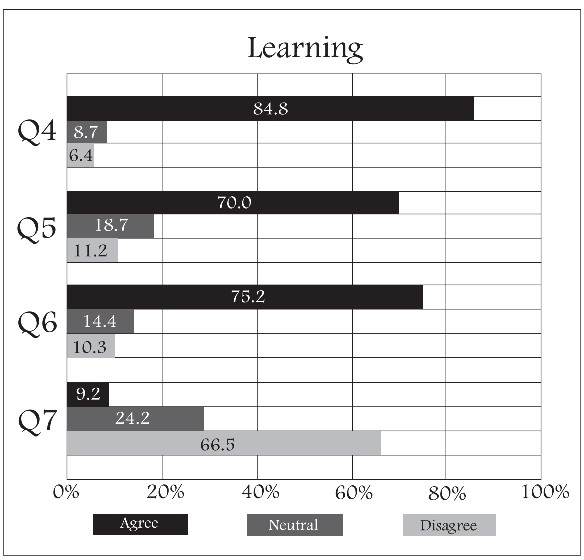
Learning

[Q4] Using clickers helps the teacher to become more aware of student difficulties with the subject matter.

[Q5] I have to think more in classes with clickers than in traditional lecture classes.

[Q6] Hearing other students explain problems in their own words when working in our small groups helps me to learn.

[Q7] I remember less after a class with clickers than after other classes.



Interaction and Discussion

[Q8] I got to know fewer students than I usually do in a traditional class.

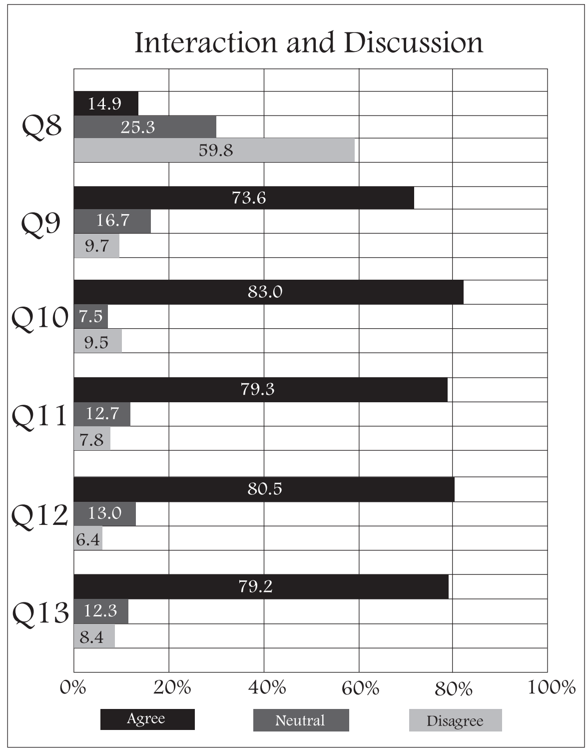
[Q9] I think that anonymous participation is a good idea.

[Q10] I am more actively involved during classes with clickers than during traditional classes.

[Q11] *Discussing* clicker questions with other students in the class helps me to understand better the subject matter.

[Q12] Team members were actively involved in solving the questions.

[Q13] Collaborative work among group members contributed to a better quality solution to the problems.



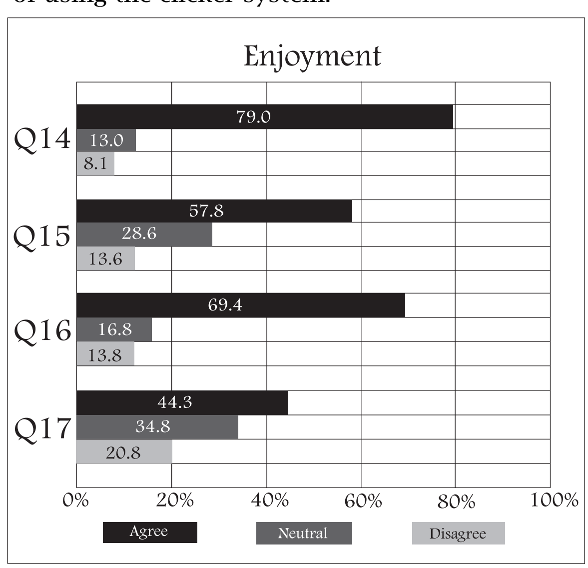
Enjoyment

[Q14] Using the clickers helps me enjoy this class more than I enjoy traditional lecture classes.

[Q15] Seeing the class responses to a concept question (histogram) helps increase my confidence.

[Q16] The clicker approach should be used for other subjects.

[Q17] I am more likely to attend class because of using the clicker system.



In the surveys at Northwestern, and several other published studies ([5], [6], [7]), students believed that the use of clickers made them more aware of their misunderstandings and helped them to understand what is expected in class. They also felt that they were more involved in classes using clickers than traditional classes. Moreover, discussion with other students helped students to understand and learn the material. Finally, they reported that clickers made class more enjoyable. Another advantage from the instructor's perspective is that students are more eager to participate in "follow up" class-wide discussions after engaging in peer-to-peer discussions.

Several studies have found increased interest, motivation, and retention in classes that use clickers ([7], [8]). Harvard physicist Eric Mazur compared learning gains in his classes with and without clickers. In clicker-classes, students discussed their answers with their neighbors before and after responding to clicker questions. Mazur found that physics students within the clicker setting made larger gains on standardized physics tests than the control group without clickers [9]. A recent study by Lasry [10] found students who used flashcards to respond made gains equal to those made by students using clickers. This suggests that it is not the technology itself that is responsible for gains in learning but the pedagogy of engaging students during class, requiring them to engage in peer-to-peer discussion before responding with the clicker, and giving them immediate feedback.

The use of clickers is not without its limitations. Mid-range clickers generally cost between US$20–US$60 per unit. As with all technology, trouble shooting problems can be frustrating and time-consuming. For instructors, additional class planning time is needed for preparing the questions and technology. Some instructors feel that the class time spent on clicker questions reduces the amount of time available to cover additional content. In our experience, the depth of student engagement with the content compensates for the reduced time to cover a wider breadth of material. Despite the drawbacks, we feel the advantages of using the technology outweigh the disadvantages. Although clickers may not make students fall in love with calculus, they may help them to be more engaged in calculus classes, which in turn may enhance learning.

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