now we're really CLICKING!

Using clickers in a high school mathematics classroom—before, during, and after instruction—provides data on students' understanding and attitudes.

Susan R. Popelka

Forty-five percent of my precalculus students know how to find the limit of a function algebraically. Eighty-three percent know how to find the limit of a function graphically. Two students feel that limits are very challenging. Fifty-two percent think that I should slow down when presenting new material on limits. Sixty-eight percent think that the homework on limits is challenging and worthwhile. One hundred percent think that the interactive response system I use in my classroom is helping them understand precalculus better.

PHOTO COURTESY OF SMART TECHNOLOGIES

Interactive response systems go by a multitude of names—clickers, polling devices, automatic hand raisers, "those cell phone thingies." The clicker that I use with my precalculus students and that is referenced in this article is a Senteo™ (made by Smart Technologies but no longer in production). This clicker is one of several types widely used in K–12 classrooms, each of which has its own variety of features and options. However, the brand of clickers used is not nearly as important as *how* they are used to increase student learning and to drive instruction.

Using presentation software, the teacher creates questions (multiple-choice, yes-or-no, or numerical questions) that are integrated into the daily lesson. Questions can be written before a lesson or spontaneously during class discussions (instantaneous questions). Questions can be grouped together at the beginning or at the end of the lesson or interspersed throughout.

At the beginning of the lesson, students turn on their clickers and enter their identification numbers. Using the presentation software, the teacher displays a question on the projector screen; students choose their answers and enter them using the clickers. The class responses can be displayed immediately as a pie chart or a bar graph to show what percentage of the students picked any given response. The teacher can even find out who picked an individual response, in what order the students answered the questions, and who has not yet answered the question.

After the lesson, the results can be exported to a spreadsheet and printed. The teacher can easily see how an individual student answered a particular question, what questions challenged the whole class, and how individual students performed on a set of questions.

BEFORE THE LESSON

Before starting a unit, the teacher can ask questions to assess students' prior knowledge and preparation. I generally ask two or three questions that gauge whether students have the prerequisite skills for the new topic, whether they have already been exposed to the topic, and whether they have a basic understanding of the topic.

Figure 1 shows an example of a question that I ask the class before beginning a lesson on functions. Students can answer these same kinds of questions without using clickers, but it is often hard to judge by a show of hands which students actually have prior knowledge. Sometimes students are reluctant to raise their hands to admit they know (or do not know) something about a particular topic. When using clickers, students can answer the questions privately. After class, I will look carefully at the data to determine which

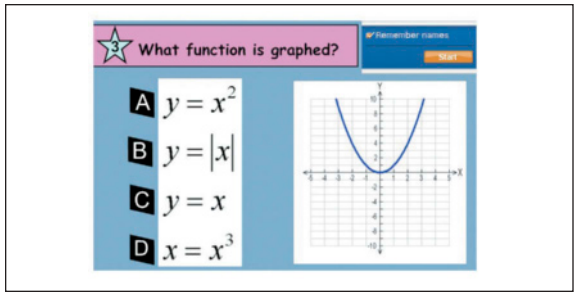

Fig. 1 For this pre-instruction question in a lesson on graphs of functions, the correct answer is A.

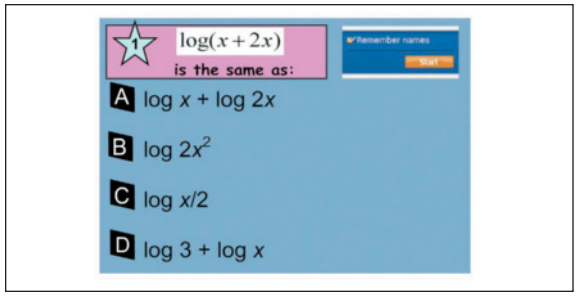

Fig. 2 I typically ask this question during instruction on laws of logarithms. The correct answer is D.

students will need extra help and, given what the data show about what students have retained from previous instruction, how to prepare for the following day.

DURING THE LESSON

Following class discussion on a new topic, I will ask several questions to see whether students have grasped the concept. Multiple-choice questions are composed very carefully to include choices that students would pick if they made a common error for that particular problem.

After students answer the question, class results are displayed as a pie chart. Students are asked to explain how they reached the correct answer, but discussions that center on how students obtained an incorrect answer are equally important. A nonthreatening way to address how students arrive at wrong answers is to have them complete the statement, "Answer B would be the right answer if …." This technique shows students where their errors occurred and also gives other students the opportunity to teach and to think critically.

Figure 2 shows a typical question that I present in a lesson on laws of logarithms; the correct answer is D. Students who are prone to look at the numbers in the question to find similar numbers in the answers will struggle with this question. Many students picked answer A for this question, even though we had just finished discussing how the log function cannot be distributed. We had even worked through several specific examples on calculators in small groups to illustrate this. Using

clickers exposed a lot of misconceptions about this particular property of logarithms. In addition, some errors in reasoning would never have surfaced without the use of clickers and the classroom discussion that they initiated.

The clicker questions are used during instruction to guide and to stimulate learning. If students are grasping a topic well, according to their answers to clicker questions, I can immediately change the lesson plan rather than continuing to teach material that is already well understood.

Students will often help one another with questions. The discussions that occur as students work together are very worthwhile and happen naturally when using clickers. Students know that the purpose of clickers is not to penalize them for getting the wrong answers; it is to encourage them to learn in an unintimidating and cooperative way, to help one another so that they make progress individually and as a group.

Most of the clicker questions that I ask during my precalculus classes are ones that I have written ahead of time, but I use instantaneous questions as well. For example, during a unit on fractional expressions, students were having a hard time with division problems. They had forgotten how to divide simple fractions, so I inserted a couple of division problems as instant questions. The data showed that the next day's lesson would have to be modified to include some review on operations with fractions.

Students can write their own questions and then display them using a document camera, an activity that gives students the chance to think about common errors and how to avoid those mistakes themselves. One way to conduct this activity is to divide the class into groups of four students. Each group is given a concept from the unit and instructed to write a multiple-choice question that assesses understanding of that concept. Students should choose answers for the multiple-choice questions that represent the types of errors other students would make.

> EACH GROUP DISCUSSED NOT ONLY THE RIGHT ANSWER BUT ALSO—AND OFTEN MORE IMPORTANT—THE WRONG ANSWERS.

The students whose work is shown in **figure 3** were asked to write a question that assessed understanding of the graphs of exponential functions. This activity made the students dig deeply into their understanding of the material. Each group of students presented its question to the class and then led a discussion of the problem, discussing not only the right answer but also—and often more important—the wrong answers.

AFTER THE LESSON: THE NEXT DAY, WEEK, OR MONTH

Clicker questions can also be used to determine how well students have retained material. I use questions at the end of a lesson or on the following day as an immediate review and to see whether students are ready to move on to the next topic.

Clicker questions can be used before quizzes or tests as review and also several weeks later to make sure that students retain information as they move on to new topics. **Figure 4** shows a review question for a unit on products of algebraic expressions and factoring. Many students picked answer A because they persisted in the misconception that a binomial can be cubed by simply adding the cubes of the first and last terms. When students were asked to use a simple problem to explain why the first answer would not work, one student said, "Answer A would be right if $(2 + 3)^3 = 2^3 + 3^3$."

Clicker questions can be used for graded assessments; in fact, assessment is one of their main marketing features. However, teachers should be aware of some inherent problems when using the clickers

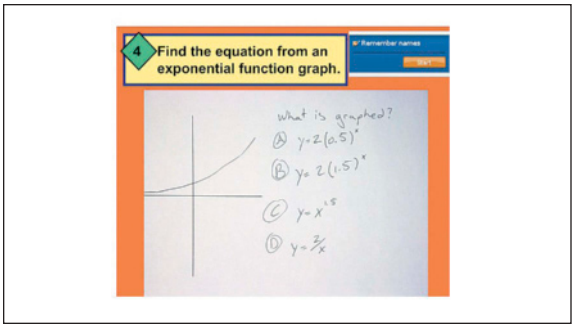

Fig. 3 Students wrote this question and displayed it using a document camera. The correct answer is B.

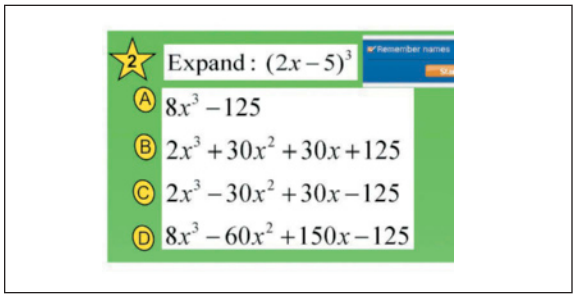

Fig. 4 For this review question in the unit on products of algebraic expressions, the correct answer is D.

for grading purposes. One problem is that when problems are projected one at a time or even as a group, some students will take longer than others to answer the questions. A way to avoid this discrepancy is to distribute the actual questions ahead of time as a handout. When all students have finished, the questions can be projected one at a time on the screen, and students can use the clickers to enter their responses.

A second problem with grading students when they use clickers is that students sometimes push the wrong button to enter their response. When students know that their responses are being graded, the stress of pushing the proper key seems to be unavoidable. A work-around for this problem is to have students circle the incorrectly "clicked" question on the handout with the printed questions and hand that in. However, my students did not like using clickers for grading purposes; they felt very strongly that this intention made using them less fun.

THE MOST DRAMATIC EFFECT IS ON STRUGGLING STUDENTS WHO SIT BACK AND LET SOMEONE–ANYONE–ELSE IN THE CLASS DO THE WORK.

PERCEPTION QUESTIONS

Most of my lessons include clicker questions related to these:

- How challenging was the lesson?
- How confident are you in your mathematics skills?
- Is the pacing right?
- Is the assigned homework worthwhile?

When a teacher asks these types of questions, it is generally a good idea *not* to show the results to the class. If students are intimidated by the responses, they will be less likely to answer truthfully in the future. A student who sees that he or she is the only one who finds the material difficult might be persuaded to select "just right" on future perception-type questions.

The answers to these questions can be very revealing and show students' perceptions about mathematics in a variety of ways. These questions provide valuable information to help me reflect on my teaching and the students' learning; they make the lessons data-driven instead of opinion-driven. **Figure 5** shows an example of a question I asked after a lesson on exponential functions.

Clicker questions are appropriate for assessing students' perceptions about their prior mathematical knowledge. **Figure 6** shows a question I asked before a lesson on factoring. Asking this type of question identifies students who will need extra help in the unit. Imagine asking this question without using clickers. How many high school students would admit to being at either extreme of the continuum?

I always ask an American College Testing (ACT) clicker question of the day. After responding to the question, students discuss problem-solving techniques, the benefits of certain approaches over others, and test-taking strategies. Data from the results of the ACT prep questions can be used to show where gaps in retention and instruction exist so that teachers know what needs to be emphasized more and reviewed periodically in their school's mathematics curriculum.

STUDENT ENGAGEMENT AND PARTICIPATION

When I asked a student recently what the best thing about using clickers is, she responded, "I never like raising my hand in class. [Clickers]

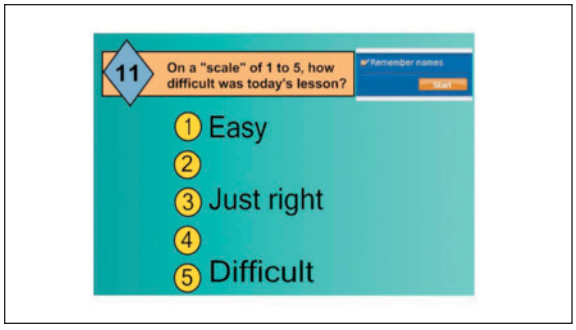

Fig. 5 This perception question is one I ask in a unit on exponential functions.

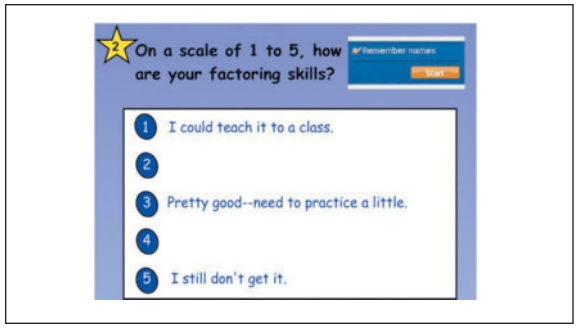

Fig. 6 This perception question helps me assess students' current skill level.

make me participate without having to raise my hand." This student is not alone in her reluctance to raise her hand. Students generally do not want to stand out as either being intelligent or having academic difficulties, so they opt for not volunteering answers at all. Or they let one person answer for all of them; in this case, class instruction becomes a dialogue between the teacher and one or two "smart" students. With the clickers, students cannot sit back and be passive learners.

When students were asked whether using clickers made them feel that they were participating more fully, their responses included the following:

- "I feel more involved in class. [Using clickers] encourages me to work out the problems instead of waiting for someone else to always do them."
- "It lets everyone get involved, and the teacher knows if all the students are done doing the problem."
- "Makes me apply myself more. I pay attention more."
- "Because of them I participate every time we use them."
- "It makes me feel like I am not being judged by others."
- "Yeah, totally, because your answer contributes to the class average."

The last student comment is interesting because I had not anticipated that effect when I started using the clickers. I was concerned that students might not take the questions seriously because I was not using the results in grading. What I found was that students wanted the class average to be high on every question: There was a real sense of wanting to perform well as a group. Students started helping one another more, and student participation in partner and group work in other class activities improved noticeably. The fact that students wanted to perform well on the questions might also be related to their previous experience with video games in which they try to get the highest score (I have heard several students make comments during class that support this conjecture).

EFFECT ON LEARNING

Student engagement and participation naturally influence learning, increase achievement, and promote positive attitudes about mathematics. One frustration I have had in teaching mathematics is student motivation. I encourage students to try problems before deciding that they simply cannot do them, and the clickers provide a user-friendly and fun way for students to attempt problems that they might otherwise disregard.

I have analyzed the data from question sets for the past year, and my analysis has not revealed a single student who has "checked out"—that is, who has given up on the questions. Each question appears to be a new challenge to be "passed," much like levels in students' video games. The most dramatic effect that using clickers has had in my classroom is on the struggling students, the ones who sit back and let someone—anyone—else in the class do the work. Clickers allow even struggling students to become an integral part of the class instead of remaining outsiders.

Since I started using clickers, the grade averages of my classes have increased significantly. I am able to teach at a higher level because I can immediately assess where students are without spending needless time on reviewing material they already know. Students are retaining more concepts. And they are enjoying mathematics. When asked whether they thought using clickers made precalculus easier to learn and whether they learned more, students gave the following responses:

- "It's nice to know immediately if I'm right or wrong and how my answer compares to the rest of the class. It gives me confidence when I am right."
- "I like the option of answering a question without everyone knowing your personal answer."
- "They turn Precalc into kind of a game! Plus it's obvious if I know what I'm doing or not."
- "It helps me see what mistakes I made easier."
- "It helps me find out what I need to work on."

When I first started using clickers, my intent was to assess student learning and to obtain data that would drive my instruction. I also wanted to obtain data on students' perceptions of mathematics. Clickers have more than fulfilled these primary goals. Many of the effects that clickers have had on my classroom were unanticipated, but all have been extremely positive.

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