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Part I An Introduction to Teaching Mathematics with Classroom Voting

Introduction 3

In this paper we explain the inspiration for this volume, and discuss each paper in turn, explaining how they relate to each other.

1 Teaching Mathematics with Classroom Voting 5

By Kelly Cline and Holly Zullo

What is classroom voting? What is the evidence that this teaching method works? How exactly does classroom voting change the learning experience? What can you do to use classroom voting most effectively? In this broad introduction to classroom voting in mathematics, we explain the rationale for voting, and give specific advice for how we make this work in our own classes.

2 Key Issues in Classroom Voting 9

By Holly Zullo, Kathy Gniadek, Derek Bruff, and Kelly Cline

In this paper, the various authors present opposing points of view on three subjects: Is it better to do classroom voting with clickers, or without them? Is it better to vote each question twice, once individually and once after small group discussions, or is one vote per question sufficient? Should classroom voting be counted towards a student's grade, or does the pressure of grading stifle discussion?

Part II Studies of Classroom Voting in Mathematics

3 Can Good Questions and Peer Discussion Improve Calculus Instruction? 15

Robyn L. Miller, Everilis Santana-Vega, and Maria S. Terrell

This chapter reprints the report from the Cornell GoodQuestions Project, originally published in PRIMUS in 2006. This study involved 330 students enrolled in 17 sections of calculus, taught by 14 different instructors, who each chose how they would use classroom voting, if at all. In the end, the study found that the students in sections using deep questions and lots of discussion did significantly better on the final exam than those without voting, or those where voting did not include small group discussions.

The full text of this chapter is only available in the print version of this book.

4 Using Peer Instruction and i-clickers to Enhance Student Participation in Calculus 21

By Adam Lucas

This study, also originally published in PRIMUS but modified for this volume, concerns the use of classroom voting in calculus. The author examines the effect of certain high status students within small group discussions, and how they may dominate discussions, persuading other students to vote with them, even when the high status student is in error. He finds that if students are instructed to write down their reasoning on paper during small group discussions, they are less likely be erroneously persuaded by high status students.

The full text of this chapter is only available in the print version of this book.

- 5 Student Surveys: What Do They Think? 29**
By Holly Zullo, Kelly Cline, Mark Parker, Ron Buckmire, John George, Katharine Gurski, Jacob Juul Larsen, Blake Mellor, Jack Oberweiser, Dennis Peterson, John Scharf, Richard Spindler, Ann Stewart
 This paper describes the results from a post-course survey about classroom voting involving 513 students in 26 classes, taught by 14 instructors at 10 different institutions. Overwhelming majorities of students said that classroom voting is fun, it helps them engage in the material, and it helps them learn. More than three-quarters of students surveyed said that they would choose a section of a course with voting over one without it.
- Part III Classroom Voting in Specific Mathematics Courses**
- 6 Questions to Engage Students in Discussion (Q.E.D): Using Clickers in a Mathematics for Liberal Arts Course 37**
By Raymond J. McGivney and Jean McGivney-Burelle
 Here, the authors discuss their use of classroom voting in a liberal arts mathematics class. They discuss their different uses of voting in this course, and explain how they came to write questions for the specific purpose of engaging students in discussion, then present feedback from both students and faculty on classroom voting in this course.
- 7 Clickers in Introductory Statistics Courses 43**
By Teri J. Murphy, Curtis C. McKnight, Michael Richman, Robert Terry
 This paper reports on an NSF-funded collaboration between faculty from mathematics, meteorology, and psychology to write and test a set of classroom voting questions for introductory statistics. Each of the four authors presents an example lesson plan with voting questions. Their plans include the following topics: “Box and Whiskers Plots,” “Hypothesis Testing,” “Expected Values,” and “Methods for Reporting Statistical Results.”
- 8 Using Clickers in a Statistics Classroom 53**
By Brenda K. Gunderson and Herle M. McGowan
 These authors discuss three different ways they use classroom voting in large introductory statistics classes of 60 to 400 students. They present example lesson plans illustrating each. In “Using Confidence Intervals to Test Hypotheses,” they test student understanding of recently covered material. In “How to Look at your Data,” they use voting to address common misconceptions. In “Testing about a Population Proportion,” they collect data from the students to illustrate methods of analysis.
- 9 Engaging Statistics Students with Classroom Response Systems 61**
By Derek Bruff
 Derek Bruff’s principal goals in using classroom voting emphasize generating discussion, developing conceptual understanding, and creating “times for telling” in which voting results reveal errors in student thinking and surprise the students, so that they are curious and motivated to discover their mistakes. In this paper he discusses voting questions that can be used to support each goal, in the setting of a statistics class.
- 10 Incorporating Clicker Technology in the Introductory Statistics Course 71**
By Roxy Peck
 Roxy Peck explains what she has learned about writing effective clicker questions for her statistics classes, finding that the questions and each of the incorrect options available must be designed very carefully, to give specific information to the instructor about the nature of student misconceptions. She further presents the results of an informal study, comparing two sections of introductory statistics that she taught during the same term, one with clickers and one without, finding that clickers appear to have a positive effect on both student performance and attitudes.

11 Using Clickers in Courses for Future K–8 Teachers 77*By Kathryn Ernie, Sherrie Serros, and Erick Hofacker*

This paper reports on the use of clickers in courses for prospective teachers, finding that voting can launch discussions about misconceptions, misrepresentations, and student reasoning in general. They present an annotated lesson plan on multicultural games of chance and show how voting can help create a discussion where students recognize different ways of representing the same scenario. Further, the authors find that voting can help students become more reflective about their own learning process, which is especially important for future teachers.

12 Using Clickers in Professional Development Workshops 83*By Sherrie Serros, Erick Hofacker and Kathryn Ernie*

The authors explain how they used classroom voting in a workshop for teachers in order to promote different types of discussions. They used voting to address specific misconceptions or gaps in the teacher's knowledge, to make the teachers aware of the results from national tests, and to conclude a mathematical experiment in which students graphed the height of water as a function of volume in vases of different shapes.

13 Using ConcepTests in College Algebra 87*By Mark D. Schlatter*

Schlatter uses classroom voting, where individual questions are called ConcepTests, to engage students and provoke discussion. Here he presents questions used in four ways in his college algebra classes: connecting multiple representations, making valid inferences, interpreting mathematical data, and motivating new material.

14 An Example of Multi-Purpose Use of Clickers in College Algebra 93*By Lee R. Gibson*

Gibson discusses his use of classroom voting in college algebra classes with up to 150 students. He presents a complete sample lesson plan on *Linear Relationships: Slope and Average Rate of Change*, including reading questions, basic skills voting questions, and a series of three questions that ends in a deep discussion question. He discusses how the components of this lesson plan fit into the larger framework of his course.

15 ConcepTests—Classroom Voting: A Catalyst for an Interactive College Algebra Classroom 101*By David O. Lomen*

Lomen discusses voting questions for a wide variety of college algebra topics, including polynomials, rational functions, and scaling and shifting graphs. Some of these questions are designed to introduce a topic, while others are used afterward, for review and diagnosis of misconceptions. He concludes by discussing his reasons and methodology for voting without clickers.

16 Using Clickers to Encourage Communication and Self-Reflection in Precalculus 107*By Erick Hofacker, Kathryn Ernie, and Sherrie Serros*

The authors carefully discuss three particular voting questions they used in their precalculus classes, detailing how the questions were used and what types of reasoning and communication they have seen expressed by their students when discussing these questions. In particular, these questions illustrate three different purposes for voting questions: introduce a topic of which students may have previous knowledge, revisit and generalize material that had recently been discussed in class, and help students recognize when more information is needed to solve a problem.

- 17 Writing and Adapting Classroom Voting Questions: New Functions from Old 113**
By Lahna VonEpps
 Recognizing that existing sets of classroom voting questions can be very helpful when constructing a lesson plan, but still may not provide everything one needs, VonEpps discusses how she prepares a lesson utilizing questions from an existing set and supplementing with questions she writes herself. Her lesson is on precalculus topics, covered at a review pace at the beginning of a differential calculus course.
- 18 Enhancing Student Participation and Attitudes in a Large-Lecture Calculus Course 121**
By Angela Sharp
 Sharp discusses her use of voting in calculus classes with over 150 students. She explains some of the implementation details for classes of this size, such as how to display questions and responses and how she assigns a participation grade. She gives several example questions that she uses in her classes, and shares how she manages discussions in a large-lecture course.
- 19 Good Questions for Mathematics Education: An Example from Multivariable Calculus 127**
By Maria Terrell
 Terrell discusses a series of questions on flux that was developed under Cornell's NSF-funded Good Questions project. She pays particular attention to using questions to draw out what students already know from everyday life, and using that to help them develop a deeper understanding of calculus concepts.
- 20 Integrating Classroom Voting Into Your Lectures: Some Thoughts and Examples Centered Around a Differential Equations Course 131**
By Christopher K. Storm
 Storm describes how he prepared lesson plans for his differential equations class by starting with classroom voting questions drawn from an existing collection, and then supplementing these with questions that he wrote himself. He presents two lesson plans; one was for a typical class period with a few voting questions scattered throughout a more traditional presentation on the topic of forced second order differential equations. The other lesson plan was for an experimental day, involving almost exclusively voting questions and discussion, on the topic of analytic solutions of homogeneous systems of differential equations.
- 21 Classroom Voting Questions that Provoke Teachable Moments in Differential Equations 141**
By Kelly Cline, Holly Zullo, Mark Parker, John George, William Harris, Ann Stewart, and Christopher Storm
 The authors used voting statistics to identify questions in differential equations where on average, less than 50% of students voted correctly. In this paper they examine several questions that focus on fundamental issues in differential equations, including units, Euler's Method, equilibria, solutions to nonhomogeneous differential equations, uniqueness of solutions, and systems of differential equations.
- 22 Teaching Linear Algebra with Classroom Voting: A Class Period on Linear Independence 149**
By Kelly Cline
 Cline presents details of the voting questions and the discussions they generated in a class period on linear independence. Illustrating with the three voting questions from that class period, he describes in depth how he leads a post-vote discussion that draws rich ideas from the students as they discuss the significant concepts of the day.
- 23 Lesson Planning with Classroom Voting: An Example from Linear Algebra 153**
By Holly Zullo
 Zullo discusses how to write a flexible lesson plan using classroom voting, keeping in mind that we need to be prepared for student discussions of varying length. She illustrates her ideas with a lesson on matrix multiplication and matrix inverses, with a summary of the student discussions on each question and how that affected her teaching decisions.

24 Using Clickers to Enhance Learning in Upper-Level Mathematics Courses	159
<i>By Patti Frazer Lock</i>	
Classroom voting has been implemented most widely in service-level courses, through calculus, and more recently including linear algebra and differential equations. Patti Frazer Lock shows us how voting can be used in upper-division mathematics courses, specifically Introduction to Proofs and Abstract Algebra, with great success. She presents several questions for each class, and she discusses the benefits she has found from using voting at this level.	
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