Interactive Instruction, Remediation, and Research
in Freshman Calculus via Pen-Technology
and Web-based Software

Abstract

Too many students in Freshman Calculus are unprepared for the pace at which new concepts are introduced, are unable to implement prerequisite Algebra skills, and are unwilling to seek answers to their questions in front of their classmates. We report on how the Department of Mathematical Sciences at Clemson University, through a partnership with the Computer Science Department, has used Tablet PCs and the web-based interactive software, MessageGrid, to address these issues over the past four semesters. Pen-technology in large-enrollment content-heavy Calculus courses provides new ways to communicate with struggling students: projection of anonymous student-inked submissions; "personalized" feedback on group activities; student-generated audio-video podcasts; in Fall 2008, quick identification and remediation of weak algebra skills via inking on Mathpad, and in Spring 2009 through an NSF grant, tagging of student errors in inked responses. We report a higher percentage of students able to enroll in second-semester Calculus. Despite this emerging evidence of greater student success and despite very positive faculty and student perceptions, it is not easy to expand the set of math faculty willing to try the technology. Yet, interest in Tablet PCs (and MessageGrid) is flourishing at Clemson, due to a 2007 Hewlett Packard Leadership Grant which placed Tablet PCs into a multidisciplinary technology classroom and attracted faculty from Engineering and other departments willing to invest time to learn new pedagogical techniques.

Introduction

Approximately 20% of students in first-semester Freshman Calculus at Clemson University in Fall 2007 earned Ds (poor), Fs (fail) or Ws (withdraw) and either had to repeat the course or abandon their STEM career goals. This DFW rate represented nearly a 50% reduction in the rate from Fall 2005, attributable to a new instructional model and a new placement procedure implemented by the Department of Mathematics in Fall 2006. All sections of Calculus I adopted a variation of the SCALE-UP active-learning instructional model which includes short lectures, student collaboration at round tables, and graded group activities. The placement procedure was altered so that more students had to enroll in "Long Calculus," a one-year course interspersing Algebra review into a slow-paced Calculus I. Performance statistics (like the 20% DFW rate cited above) indicate that these have been important improvements, but we have not stopped there in trying to address the needs of at-risk students. With a 2006 Hewlett-Packard Technology for Teaching grant, we placed Tablet PCs into several sections of a Freshman Liberal-arts Math course and found that student perceptions, behavior and performance (especially of weaker students) improved. By placing these Tablet PCs and others, obtained through a 2007 Hewlett Packard Leadership Grant, into the first semester of Freshman Calculus, we can reach a significant portion of that intractable group of students who fall behind early and fail to earn the C or better needed to move into Calculus II second semester.
Instruction and Active Learning

If a student engages in the classroom, works problems and receives feedback, he is more likely to take charge of his learning outside of class, do the homework and not fall behind. The active classroom is widely promoted in Mathematics, Engineering, and other sciences. In Calculus I, there are 45 students with one HP Tablet PC assigned to each group of 2-3 students. In each class a different member of the group signs in as the "recorder" for the group who inks that day's solutions. Since class meets 4 times a week, every student is a recorder at least once a week. Short lectures are interspersed with two or three problems that each recorder solves (with input from his group) and submits on the Tablet PCs, using the software, MessageGrid. MessageGrid allows the instructor to create a grid before class or spontaneously, with questions in columns and group answers in rows. The instructor can quickly scroll through "anonymous" submissions and choose a few to project and discuss (e.g., those with interesting errors or notational issues).

When explaining a concept in the context of correcting a student mistake, the instructor taps into students' natural curiosity about how their peers are doing in the class. (Without pen-technology, the instructor would walk around bending to look at a few papers and commenting on errors in a way that benefits only that student and maybe his neighbor.) Our current lecture-submission routine highlights a manageable list of new skills that will be the focus of the group activity following the lecture. During the group activity, students work together and the recorder inks and submits their agreed-upon solutions into MessageGrid. This work is graded that day and is accessible online by the students from any computer before the next class. (See Figure 1).

Remediation

Pen-based technology can be used to identify and remedy algebra and calculus deficiencies. We use podcasts which have become a common instructional supplement. We post student-driven or student-created audio-video podcasts that are only 2-3 minutes in length. There are 4 common exams in Calculus I and, leading up to each exam, at least one podcast from each section of the text explaining commonly missed problems (chosen by the instructor or by student request) are posted on the "Pre-Exam Recording Grid." After each exam, each student group is assigned one of the ten most-missed problems from this exam and asked to create a podcast in class to upload to the "Post-Exam Recording Grid." (See Figure 2).

Remediation is also enhanced by an inking feature recently added to MessageGrid, called Mathpad. It allows the instructor to make a rapid evaluation of specific Algebra skills at various points throughout the course. The instructor identifies the algebra skills to be emphasized in the upcoming week and creates a grid testing just these skills. The instructor inks in questions (one per column), and enters an answer key for each question via a MathType equation editor which produces MathML format for efficient comparison of the answer key and the student solution. During each class, the recorder for that day will take this very short Mathpad quiz. The student will ink his work into an ink panel on the grid, and submit his final answer using the same equation editor. The program immediately grades each student's answer and provides the student with the correct answer. If the student misses any of the questions, he understands that he must take a second quiz online that evening for homework. Mathpad will send the instructor a .csv
This process will continue every week until everyone's Algebra skills are remediated. (See Figure 3).

Student Performance

We have seen emerging evidence of greater student success from both quantitative and qualitative data. Course averages and DFW rates from both the Tablet PC and non-Tablet PC sections of Calculus I, show positive results in terms of student performance and are promising. It is important to note that common exams are used in all sections of the course, and that final grades are calculated with the same weights. Class profiles (based on Grade-Point Averages, Class standing, and scores on the Clemson Mathematics Placement Test and on the Basic Skills Test) are similar in both the Tablet PC and non-Tablet PC sections, so no advantage is conferred on the Tablet PC sections through a disproportionate number of strong students. Also, the students, when registering for the course, do not know that it will involve pen-technology.

The consistently positive course averages shown below are encouraging because some class time is lost in acquainting students with the computers and the software, or in fixing small things that go awry. The DFW rates in the Tablet PC sections are the most interesting because they strongly suggest that weaker students are doing better. The best improvement in these rates is seen after faculty has had at least a semester to become comfortable with the technology. (See Table 1).

One problem we have encountered in this project is in recruiting a larger group of Mathematics faculty to try the technology. Many faculty do not want to spend time learning how to use the Tablet PCs or the software; they do not want to deal with the distribution of equipment to the students (rolling carts into class, taking out and putting back the computers, helping with logins, etc.); and they are easily frustrated by any glitch in the technology (freeze-ups, screen-resolution problems, etc.). The truth is that the technology takes little time to learn, the students know the routine after a week (they pick up the computers from the carts as soon as they enter class and login immediately), and the glitches are very few and can be remedied. One reason for placing the majority of Tablet PCs from the 2007 Hewlett Packard Leadership Grant into a new multidisciplinary technology classroom was to attract faculty from Engineering, Computer Science and other disciplines who are willing to use this technology and share ideas about how they use it. There is now a waiting list to schedule a course in this special classroom.
### TABLE 1:

**COURSE AVERAGES AND DFW RATES FOR STUDENTS IN A FIRST SEMESTER CALCULUS COURSE, TAUGHT WITHOUT AND WITH TABLET PC/MESSAGEGRID TECHNOLOGIES.** (SP 2007, F 2007, SP 2008)

<table>
<thead>
<tr>
<th>Course Averages</th>
<th>Non-Tablet PC Sections (n=935)</th>
<th>Tablet PC Sections (n=227)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SP 07</strong></td>
<td>71.7%</td>
<td>73.66%</td>
</tr>
<tr>
<td><strong>F 07</strong></td>
<td>79.3%</td>
<td>84.4%*</td>
</tr>
<tr>
<td><strong>SP08</strong></td>
<td>76.4%</td>
<td>78.5%*</td>
</tr>
<tr>
<td><strong>% of Ds, Fs, Ws</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SP 07</strong></td>
<td>35%</td>
<td>31% (17.8%*)</td>
</tr>
<tr>
<td><strong>F 07</strong></td>
<td>20.9%</td>
<td>4.7%*</td>
</tr>
<tr>
<td><strong>SP08</strong></td>
<td>23%</td>
<td>11.4%*</td>
</tr>
</tbody>
</table>

(*instructors with Tablet PC experience)

### TABLE 2:

**TABLET PC/MESSAGEGRID USER SELECTED SURVEY RESULTS (N=227). RESPONSES TO QUESTIONS GIVEN ON A SCALE OF 1 (STRONGLY DISAGREE) TO 5 (STRONGLY AGREE).**

<table>
<thead>
<tr>
<th>Survey Question</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working with a group on a <em>MessageGrid</em> activity helps me understand concepts in this class.</td>
<td>4.57</td>
</tr>
<tr>
<td>Reviewing podcasts helps me understand concepts in this class.</td>
<td>4.50</td>
</tr>
<tr>
<td>Submitting my work to <em>MessageGrid</em> during lectures helps me understand concepts in this class.</td>
<td>4.41</td>
</tr>
<tr>
<td>Viewing corrections of students’ work on <em>MessageGrid</em> during lectures helps me understand concepts in this class.</td>
<td>4.25</td>
</tr>
</tbody>
</table>

**Student Behavior and Perceptions**

Student perceptions of the technology have been positive. The highest scores (the most positive responses) were on questions about viewing other students’ work and instructor feedback on *MessageGrid*, and about using the podcasts. (See Table 2). Open-ended responses also indicated that students enjoyed using the Tablet PCs, and found that sharing responses in class anonymously enhanced their comprehesion of topics being taught. “I learned more from seeing you correct somebody else's mistakes than from reading the text or the notes.” Many students commented that they reviewed the posted material when doing homework or studying for tests, especially the graded activity worksheets and the recordings. Students frequently comment on the value of “clear and immediate feedback,” “anonymous projections” (of student work), “podcasts that are to the point,” “and “quick algebra reminders.”

Group dynamics have improved as students work together to enter solutions on the Tablet; there is increased conversation and participation. Everyone still submits a paper worksheet, but on certain problems only the *MessageGrid* entries are graded. Thus, the entries inked on the screen become the culmination of individual paper-efforts and become a visible group product, accessible online to any student in the class from any computer. The Tablet PCs enhance a team-oriented curriculum, as advocated in Engineering Education as well as in Mathematics and other Sciences, that stresses developing communication and collaborative skills, important for everyone, but especially beneficial between group members of different genders.7,8,9,10
Research and Error Analysis

In Summer 2009, we will use a new "replay" feature on MessageGrid which preserves the sequence of the student’s ink submissions, allowing the instructor to play, rewind, fast-forward, and pause the student’s ink, in a manner similar to a video tape recorder. Using a large database of students’ inked submissions collected throughout the year, we will mark/tag specific errors on each student’s submission. For example, if a student is trying to solve a related rates problem and fails to implicitly differentiate the equation properly, the instructor may mark that error with tag “T1” where T1 is defined “Ignored Chain Rule”. Tags may be pre-defined or may be created by the instructor/grader on-the-fly. Tags will be unique and a student’s submission may have several tags. Tags are more often negative (marking student errors) but may also be positive, e.g., “correct use of the Pythagorean Theorem.”

The main purpose of the Replay and Tagging Feature is to enable subsequent clustering of student submissions according to the types of errors. When a large number of student submissions have been tagged, we will conduct a post-analysis to group common errors and to draw conclusions regarding clustering of student misconceptions. Moreover, there is a remediation feature of the tags. The tags can provide feedback to each individual student when the tags are associated with a "GPS- map type marker" that allows the student to click at this location in his work and bring up a discussion of what went wrong at this point.

As a recipients of a three-year 2008 NSF-CCLI-II grant, we hope to collect thousands of samples of student pen-based submissions on a variety of Calculus problem. From the results of this “data-mining,” our goal is to create effective group activities that are scientifically-based teaching tools. We plan also to involve our local community college (Tri-County Technical College). We will collect these students’ pen-based submissions in Calculus and compare the types of errors these students make. We hope to share experiences and new materials, and to strengthen the bridge to Engineering and Science careers for Tri-County students as they move into Clemson and other 4-year Universities.

Acknowledgements

The author would like to thank the following mathematics faculty: Margaret Wiecek, Minerva Rios-Adams, Sundeep Samson, Stacy Faulkenberg, Mary Krohn, and Calvin Williams for engaging in discussions on their use of pen-technology in the classroom, and for allowing us to analyze their student submissions. Thanks to Roy Pargas and his team in Computer Science for their innovations with MessageGrid. Thanks to Lisa Benson in General Engineering for sharing her classroom experiences with the Tablet PCs, and to Barbara Weaver in Information Technology for her assistance with training and maintenance issues. Finally, we are especially grateful to Hewlett-Packard for their generous gift of the Tablet PCs.

References


