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Choosing and Adapting Technology in a Mathematics Course for Engineers

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The purpose of this report is to describe our ongoing efforts to transform a differential equations course for engineering students through a mathematical modeling approach and technological enhancements to support that approach. We believe that a large amount of mathematics learning occurs outside of the classroom and therefore outside of the traditional instructional setting. Thus, we sought instructional media that would realize our anywhere/anyplace attitude toward meeting students' needs. In our efforts to reconceptualize the course, we aimed to: (1) capitalize on engineering and science points of view to help students utilize mathematics within their discipline, and (2) use instructional technology to help the professor in achieving this goal. Mathematical modeling is theorized as a cycle that links mathematical thinking to science and engineering, and so supports the first goal. In this paper, we report on the means we used to meet the second goal and on our evaluation of our success. Our contribution to the engineering education community is (i) a description of how we can communicate this mathematical modeling process to students in ways they can learn from it any time or anywhere and (ii) an account of our experiences, decisions, and considerations as we did so.

Our Perspective on Mathematical Education of Engineering Students

Research has shown that there is a distinction in mathematical thinking between *users* of mathematics versus *teachers* of mathematics. Ferguson (2012) first made this distinction while examining tasks created by calculus professors and by professors from the disciplines that require calculus [5]. The goal was to study how they gauged whether the students comprehended a particular calculus concept. She noted that *users* of mathematics tended to focus on the questions “which” and “what is happening” (predictive and context driven) whereas the *teachers* of mathematics focused on “how” and “why” (abstract and conceptual). Others have also reported that teachers and users of mathematics prefer differing representations of derivative: mathematicians prefer to represent derivative as the slope of the tangent line versus engineers prefer to represent derivative as rate of change in quantities [1]. This kind of distinction can create mismatches in how the students are expected to know mathematics at the end of mathematics courses and how the students are expected to use mathematics in their science or engineering courses. We aim to bridge this gap in our course by using a mathematical modeling approach to differential equations.

Our course is one of two designs for a differential equations course for freshmen or sophomore engineering students. It assumes familiarity with the calculus series through multivariate calculus, but not linear algebra. The textbook for our course was designed specifically for engineering students at The Ohio State University and is built around paradigmatic engineering problems instead of analytic algorithms as the regular differential equations course is. In this way, we both address the needs of the client disciplines while continuing to provide for the mathematical education of our students within the mathematics department. Our team has already made progress in the development of this differential equations course that emphasizes mathematical reasoning within an engineering context, both theoretically [2, 8] and in practice [3, 4]. We did this through adopting a mathematical modeling approach and were guided theoretically by mathematics education research in this area, but a full discussion of the theory is beyond the scope of this paper (see, e.g., Blum & Leiß (2007)). Research has demonstrated a favorable impact on students' learning when using a modeling approach, as compared to a techniques-only approach[3]. We integrated technology as a medium to support the professor's mathematical modeling approach and to enhance the students' daily interactions with the material. Since the technology was chosen as a way of supporting a mathematical and pedagogical approach to differential equations, each of our choice for technology were considered in terms of accessibility to the students and if and how the technology might support the mathematical modeling approach of the course. Over three academic terms, we introduced a variety of technology (hardware and software). We describe how we decided on the technology, how we assessed its utility, and how we continue to assess its success in terms of helping the students connect engineering and mathematics.

The Instructional Technology

Hardware and Software Selections

In order to achieve goals (i) and (ii), we needed to to create and share models of the professor's expert mathematical modeling process in a way that would be accessible to students We selected LiveScribe's Smartpen. It generates interactive flash videos (called *pencasts*) where written work is synched with recorded audio. The resulting pencasts allow students to click on a piece of text and begin the audio and animation of the writing from that point. The pencasts are used only as out-of-class worked examples of problems from the book; they are not used during class time.

Additionally, we wished to digitize the lectures for future viewing and so during the second academic term, we chose SMART's Notebook software paired with their Sympodium. The software allowed easy preparation of slides – including mathematical equations, diagrams, and graphs – which could be modified and written upon in real time during lectures. This led to organized, nice-looking lecture presentations with the option of improvisation. The tools available with the SMART hardware and software allowed the professor to draw connections among content, for example, by using a color system to organize results of in-depth, paradigmatic problems. Moreover, the modified slides could be saved and reused as well as exported to .pdf format for later use by the students.

To realize our anywhere/anytime attitude toward access to quality mathematics content, we decided to use lecture capture and to post digital recordings of live lectures to the course website. Students were still encouraged to come to lecture (and usually did), but used the recorded lectures as an asynchronous resource. We selected Adobe Connect because of its flexibility in allowing the class to slide between a traditional lecture and a modern hybrid environment. Adobe Connect allowed us to capture and preserve the digitized lectures and allowed students at home to stream them remotely. Thus, in a typical lecture, the professor wrote electronically through a Sympodium onto his SMART lecture slides. This writing was captured alongside his voice to form a lecture capture video, which was then posted to the course webpage.

Assessment of Utility: Instrument Development

We decided to evaluate the students' use of technology electronically since our university's course website offered anonymous survey tools. Livescribe was the first software we integrated into the course and we anticipated it would be an entirely new experience for both the professor and the students. Therefore, we asked students not only about technical feedback, including visual and sound quality, but also open-ended questions about how they used the pencasts. We used the feedback from the surveys immediately to improve the pencasts and so we opted to use closed-form questions about technical details like the speed of the talk, the legibility of the handwriting, and whether the examples were helpful. We also asked open-ended questions to get a better understanding of the issues that the students were facing in using the pencasts and also to help us refine the surveys.

The surveys we used were developed iteratively over three academic terms. During weekly team meetings, we examined the results of the surveys and decided how to change the upcoming pencasts in the current academic term, which pencasts needed to be altered for the next term, and how we might modify the surveys to improve the quality of students' feedback relative to our needs. The first semester led us to further examine how and when the students used the livescribe videos.

As we introduced additional technology, we created similar technical and substantive surveys to gauge how the students were using the recorded lectures and if they were readable, acceptability of the sound volume, etc.

The students were assured that the professor would only see aggregate data never their responses to the surveys. Here is an example of the closed-form questions from our latest weekly survey on technology used during lecture and the lecture capture videos:

1. How many lectures did you attend this week? 1/2/3
2. Did you watch any recorded lectures for this week? Yes./No.
3. The clarity of the writing was: difficult to read/ mostly good but there were some parts that were difficult to read\ easy to read
4. The organization of the material was: well organized/ needs improvement/ poorly organized
5. The pace of the material was: too slow/ about right/ too fast
6. The examples used in this week's lectures were: helpful/ could have been better/ not helpful
7. Using the technology, the execution of the lectures: was great/ needs some improvement/ needs serious work.
8. The examples in this week's lectures were: enhanced by the use of technology/ about the same as a no-technology class/ would have been better without the use of technology.

We also included three open-response questions:

1. One thing from this week's lectures that was done really well with technology was:
2. The worst thing about this week's lectures using technology was:
3. One way to improve the technology lectures would be:

Evaluation

Using a mixed-methods approach, we examined the students' responses to the substantive and technical feedback surveys, documentation of our weekly team meetings, media usage data (recorded by the course website), and student academic performance data. The weekly surveys were implemented online through the course homepage and students received course credit for completing them.

We used descriptive and inferential statistics to make sense of the quantitative data and the method of constant comparison for the qualitative data. The surveys had between 10 and 31 respondents.

Results

Livescribe results

Since each weekly and midterm survey had a different number of respondents, we report percentages. Each week, after a pencast was posted, students were invited to complete a survey. The results of the pencast surveys are given in Table 1 and Figure 1 and Figure 2 below. Accesses in Table 1 was generated by counting the number of times a student clicked on a particular pencast link through the course webpage. Table 1 shows that students thought the pencasts were easy to read, had just about the right number of steps, were easy to follow, and had appropriate pacing.

Table 1. Summary of pencast surveys and accesses

Pencast #	**5**	**6**	**7**	**8**
Length	27:21	21:48	37:24	50:59
Accesses	137	139	157	138
Total Responses	63	60	63	36
Easy to Read	88%	93%	97%	81%
Right Number of Steps	84%	85%	84%	65%
Easy to Follow	94%	92%	99%	76%
Paced about right	79%	87%	90%	86%

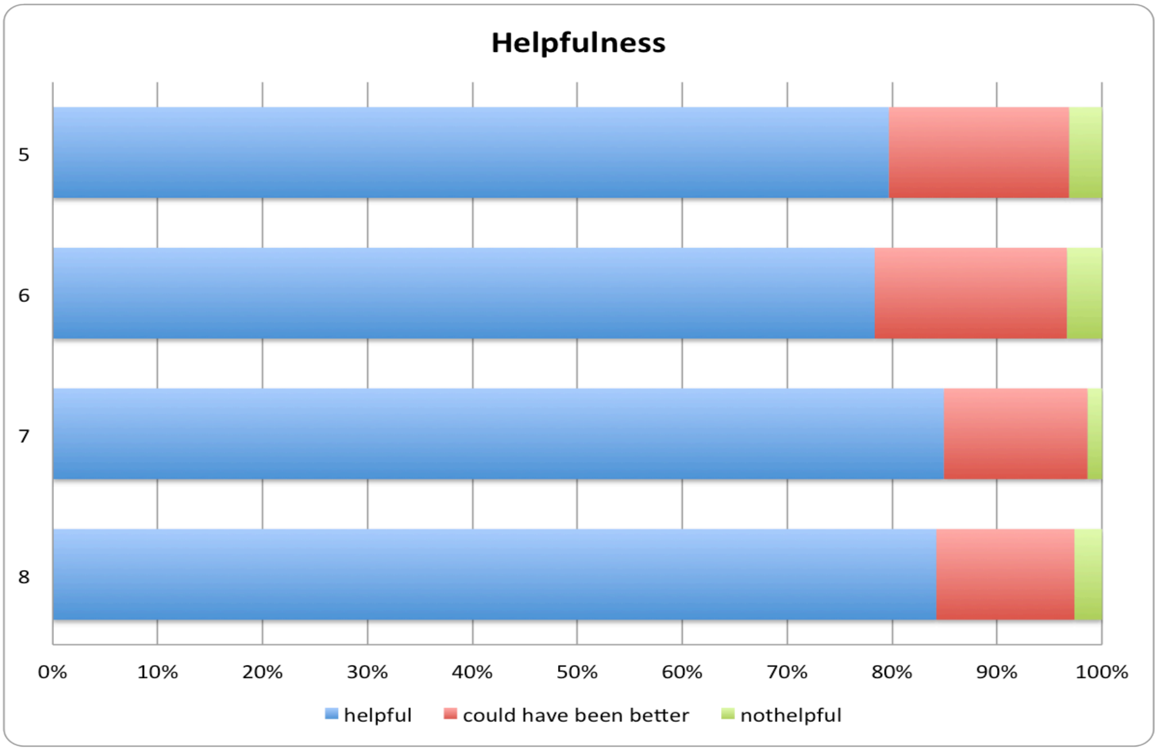

Figure 1. Student assessment of the level of helpfulness of each selected problem

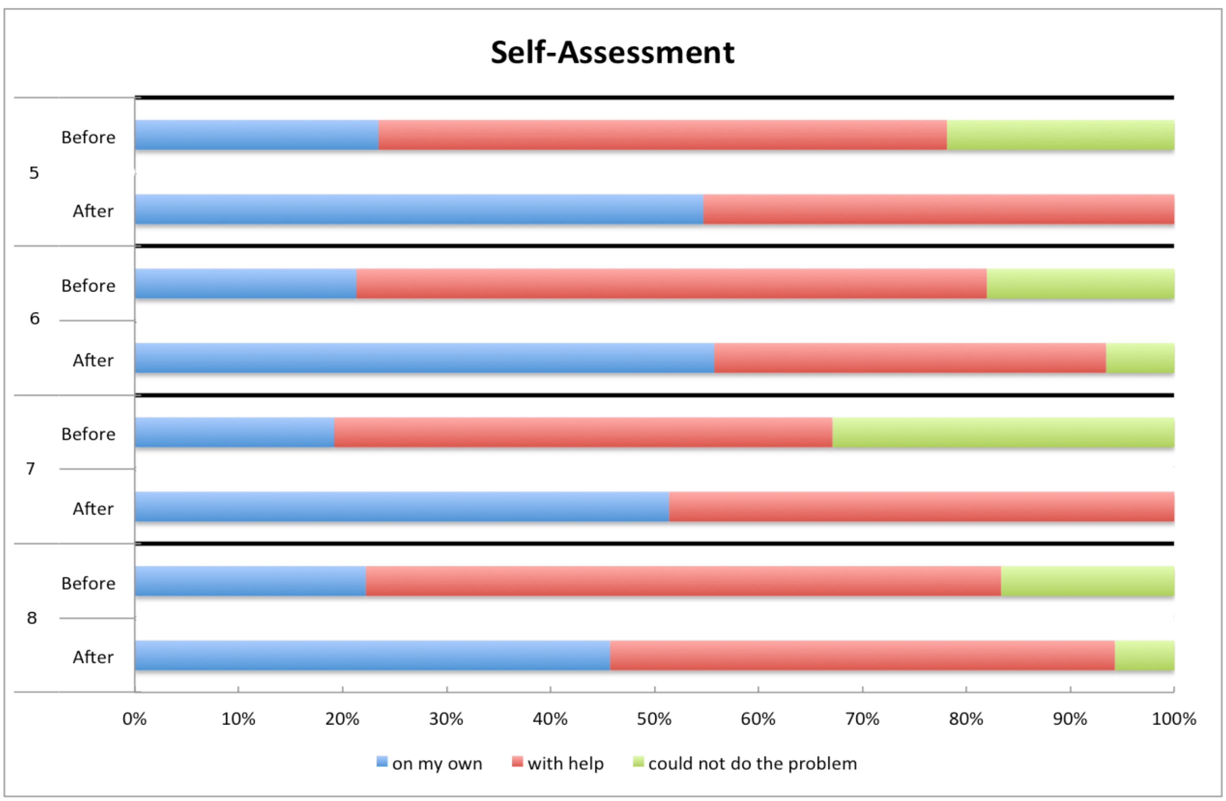

Figure 2. Percentage of students self-assessing their confidence in solving the problem independently

We also asked the students if they found the pencasts helpful (Figure 1) and if the pencasts helped them solve other similar problems (Figure 2). Figure 1 shows that the students found the problems selected for the pencasts helpful. Figure 2 shows that for each pencast, there was a shift in percentage of student viewers who believed they could solve the problem independently before and after viewing each video. For each pencast, the percentage of students who believed they could solve the problem independently after viewing the video at least doubled. Meanwhile, after viewing each pencast, the percentage of students who self-assessed as unable to solve the problem independently shrank dramatically and the percentage of students who assessed themselves as able to solve the problem with help remained roughly the same before watching the pencast and after. Since the surveys were anonymous and unmatched, we cannot determine which students improved their self-assessments and which students maintained the same view of their capabilities, but overall a great portion of the students moved forward in their confidence in solving these problems.

For usage, the most common response was studying for an exam or quiz. Students did also note that they would begin a problem, get stuck, and then watch a pencast until they understood, and then continue solving the problem.

Lecture capture results

One anecdotal argument against lecture capture is the belief that if a professor posts the lectures that students will stop coming to class. Thus in our surveys, we asked students how many times they attended lecture. The responses ranged from 60% to 100% attending all three lectures in a week with an average of 80% attendance. Thus the attendance rate from survey respondents was still reasonable.

Table 2. Survey responses about lecture capture

	1	2	3	4	5	6	7	8	9	10
Total Responses	31	16	18	15	13	10	21	11	10	15
Did Watch	68%	44%	50%	73%	46%	40%	62%	82%	70%	67%
Mostly Good to Follow	71%	75%	89%	87%	92%	80%	71%	27%	90%	93%
Well Organized	68%	88%	78%	87%	77%	60%	81%	82%	90%	73%
Paced about right	65%	81%	72%	87%	85%	60%	67%	91%	90%	40%

Table 2 tabulates results from the weekly surveys about the lecture capture technology. The total responses are lower than for the pencasts because this inquiry was conducted during the second academic term, which had a smaller course enrollment (75 students). The table records the percentage of students who reported watching the videos and whether the videos were followable, well-organized, and paced well. Consistently, one-third or more of the students were watching the videos, suggesting that at least some found them helpful as study aids. Spikes in the video usage coincide with the midterm schedule. However, in the weeks corresponding with surveys 8 and 9, the number of students reporting dropped, perhaps due to the Thanksgiving holiday and midterm from other courses. Since the surveys were self-reported it is possible that the percentage increased because fewer students reported during those weeks. In either case, the number of students reporting that they watched the videos stayed near one-third the size of the class.

Each week, except for the last, at least 60% of the students participating in research reported that the pacing of the material throughout the lecture was "about right." During the last week, pacing was rushed, likely because technology issues detracted from lecture that week. Followability of the digitized lectures improved over the academic term as the professor became more adept at using the technology and as he gained experience in visualizing how the digital lectures needed to be adapted from traditional blackboard lectures. The followability of the videos dropped in the week corresponding with survey 8, and since the students reported that those lectures were well-organized and well-paced, we interpret this sentiment to be related to the difficulty of the content.

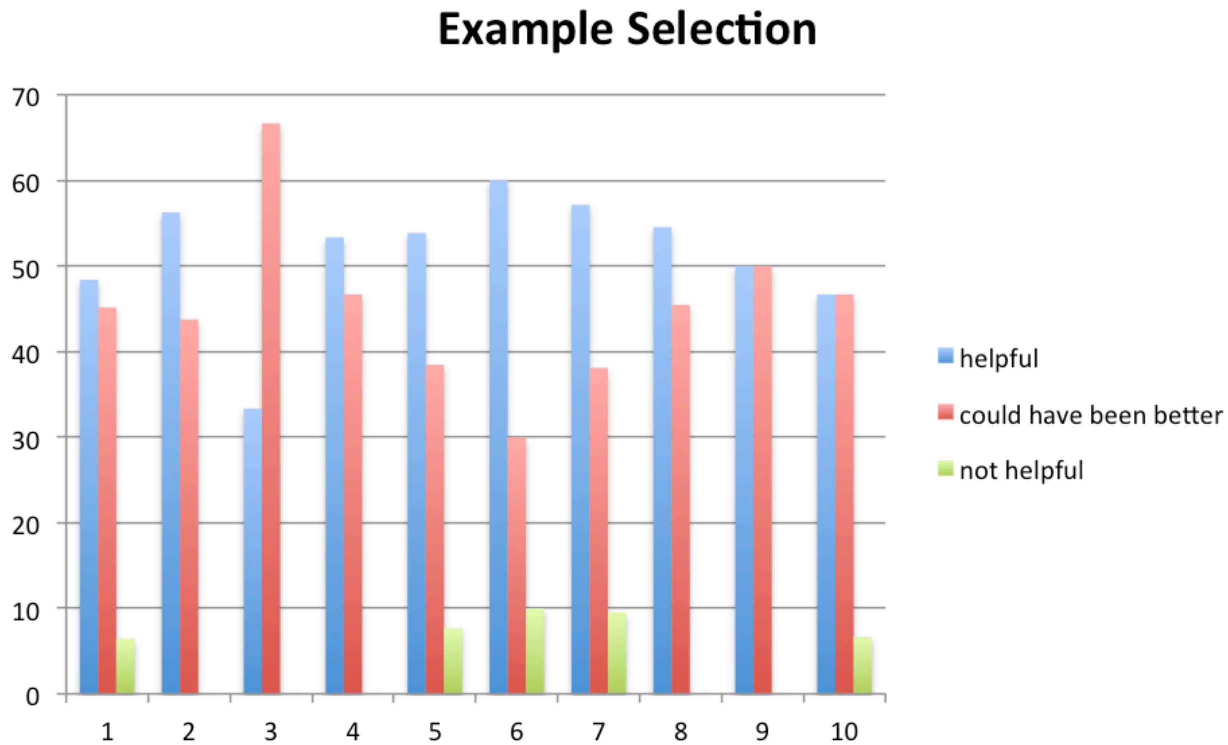

Figure 3. Percentage of students describing the helpfulness of example selection during lecture

In Figure 3, overall, students toggled between example selection being helpful and could have been better. We will ask about this further in the next semester, however, we hypothesize that part of this disparity could be due to a change in policy at our university. Recently, teaching assistants (TAs) were discontinued for this course and students could have been searching for more procedural examples rather than only the conceptual ones given during class.

The differences in lecture execution (Figure 4) can be traced to technology issues. At times, we had trouble with internet connectivity or microphone issues. For example, in weeks associated with surveys 5 and 10, we had both of these issues. Beyond connectivity and hardware issues, the transactional cost for setting up the technology at the beginning of each class was large. Even when we were able to save the necessary technology settings to the university computer, 3 programs needed to be started, a microphone needed to be attached, and files off a jump drive needed to be downloaded. We continue to troubleshoot and reflect on if our technology choices are the best or if there are other softwares available.

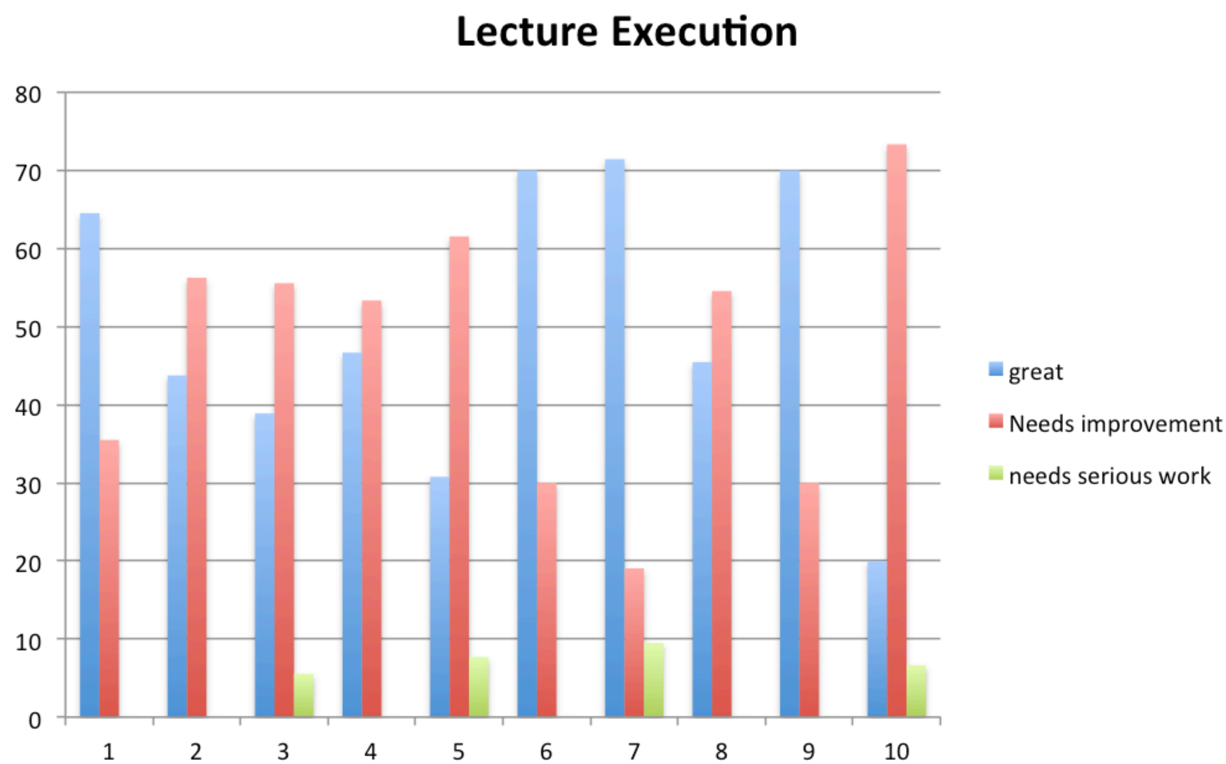

Figure 4. Percentage of students rating the execution of the lecture with technology

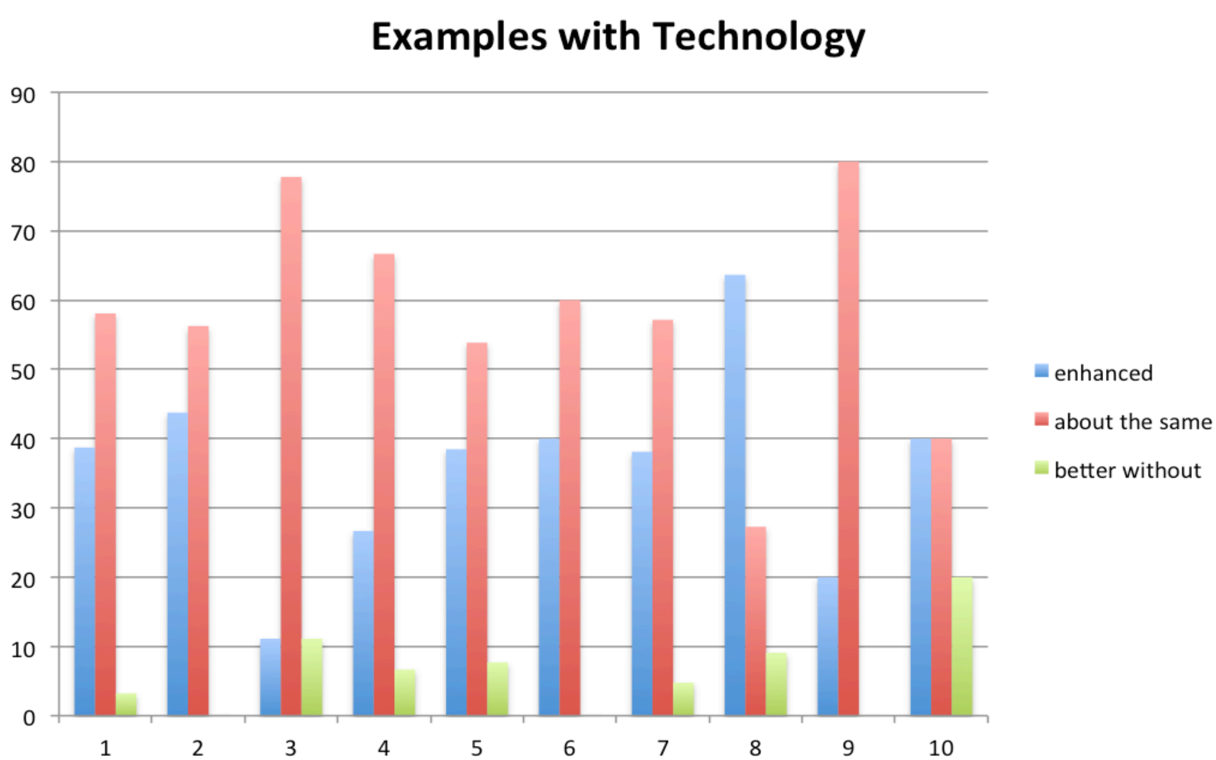

Figure 5. Percentage of students rating how examples during lecture were executed with technology

In Figure 5, students rated how the examples during lecture were executed using technology. There was a mix between the responses "about the same as with no technology" and "enhanced by technology" throughout the semester. However, qualitative responses to open ended items revealed that students appreciated being able to re-watch lectures while studying, doing homework, or filling in gaps in their notes. Thus, even though during lecture, some students thought the examples were the same as with no technology, after class, the accessibility of lectures was helpful. One student explained that the good part of recorded lectures is, "the ability to kind of lead us onto what steps need to be done next by having the blank sections of type there and I really like the recording in general. I have gone over multiple lectures multiple times and the repetitiveness really seems to help me understand more clearly."

Discussion and Conclusion

Our results suggest that the students adapted to the media quickly and found the pencasts helpful for studying or understanding similar problem contexts. For example, one student wrote, "you can see everything already there, so you can see where he's going with the solution and not just follow trying to keep up the whole time." At Montana State University, two chemistry professors used pencasts to guide their students through "iconic" problems [6]. In both our study and in Kelly's (2012) study [6], the students expressed that they appreciated being able to pause, rewind, rewatch, and work alongside the solutions at home. Since we use life-like examples that arise in engineering contexts to motivate the mathematics (see goal (1)), it is sometimes impossible to complete a problem during only one class period. This is particularly relevant to the engineering students in our course. Often, professors in many disciplines feel constrained to demonstrating only lower-level problems or ideas that they can fit into one class period. With the pencasts – and with lecture capture – longer, more cognitively challenging problems can be explored and the students can review important components multiple times at their own respective paces. In this case, the technology has enabled us to include interesting mathematics problems that have meaningful consequences in engineering contexts.

Our evaluation method made it difficult to separate students' responses to challenges inherent in the material from challenges due to using the technology. To combat this problem, in future semesters, we intend to ask an opening question about challenges specifically due to using the technology.

Our instructional technology allowed the engineering students to see full, complex mathematical modeling processes as many times and at whatever pace they choose without losing instructor interaction. The benefits are not limited to the differential equations classroom; the methods could be adapted to other engineering education contexts as well.

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