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A Departmental Initiative to Effectively Incorporate Technology Use in Engineering Mathematics Education: A Case Study

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1 Introduction

The paper presents a case study of the ongoing efforts of the department of Engineering Fundamentals at a medium-sized, urban university, to incorporate educational technology in its engineering mathematics courses. In 2007 the ABET accredited J.B. School of Engineering at the University of Louisville formed a new department, with primary focus on first year engineering education. The department teaches introduction to engineering, engineering graphics, and engineering mathematics courses, with the majority of student credit hours in engineering mathematics. Part of the department's mission is to improve retention of first year engineering students. Research has shown that for engineering students success in the first college mathematics course is critical for retention.[1–3] Therefore, a major retention effort by the department has been to improve the teaching and learning in its engineering mathematics courses using educational technologies. Many different sections and courses are taught every semester by a combination of tenure/tenure track and term faculty. The department has worked to see that the use of adopted educational technologies is reasonably consistent across courses and faculty, and that the use of the technologies persists beyond any initial pilot phase. Many factors affected the selection and adoption of different educational technologies; these included the school wide adoption of tablet PCs, participation in workshops on different educational technologies, and published literature on STEM education and educational technologies.

Determining the impact of adopted technologies on teaching and learning in the department's engineering mathematics classes presents many challenges: individual differences in students and faculty are hard to control for, course grade may not always reflect an improvement in teaching and learning, qualitative improvements can be difficult to measure, and a host of other challenges most educators are familiar with. In literature on the educational technology, results have included: cost savings, reductions in DFW rates, and student and faculty survey results.[4–6] The department is still working to develop a comprehensive assessment strategy that is well integrated with the department's strategic plan. Part of that effort it determining what data is appropriate for evaluating the impact and effectiveness of effort to use technology to improve teaching and learning. Some initial data collection and analysis has been done, and those results are presented and discussed following the initial presentation of a specific educational technology.

The department teaches freshman, sophomore, and junior level engineering mathematics classes, but the largest amount of student credit hours is in the freshman sequence: *Engineering Analysis I, Engineering Analysis II, and Engineering Analysis III*. These are calculus I, II and III courses tailored for engineering students. Educational technologies have also been adopted in upper level engineering mathematics courses, but that discussion is beyond the scope of this paper.

Over the course of the last seven years the following educational technologies have become integrated into *Engineering Analysis I, II and III*: 1) the classroom learning systems (CLS) DyKnow®, 2) Tablet PCs 3) the online interactive learning system MyMathLab® (MML), and 4) faculty developed mini video-lectures. Some of the technologies, such as Tablet PCs and DyKnow, go hand-in-hand, others like the video-lectures, are largely independent of the other technologies.

Tablet PCs and DyKnow were the first technologies to be adopted by the department. Section two explains these technologies, describes how they are used in department courses and presents the results of initial efforts to evaluate their impact on teaching and learning. MyMathLab was the next technology adopted by the department, and section three describes MyMathLab, how it has become integrated into the engineering mathematics, and presents results from initial work in assessing department use of MyMathLab. In 2013 department faculty began producing video content for *Engineering Analysis I* to replace part of weekly lecture. Section four discusses the motivation for replacing some lecture time with video content, some details of the video production, and some preliminary results in assessing the impact. A comprehensive discussion of the current impact on the department and future directions are presented in section five.

2 Tablet PCs and DyKnow (2007-present)

A Tablet PC is an ordinary notebook computer with the addition of hardware that allows for pen input, usually in the form of digital ink. The screen on a Tablet PC can be folded over onto the keyboard allowing the screen to lay flat and the pen to be used for digital inking, just like paper and pencil. In the past several years there has been an explosion of tablet devices, exemplified by the iPad™. While these newer tablet devices have much to offer, most differ from Table PCs in one or more of the following ways: they don't run Windows™, lack processing and memory sufficient to run traditional desktop applications, lack a screen of sufficient size for traditional computing, or don't include a keyboard. This maybe increasingly less true, but for the purposes of this paper a Tablet PC does not refer to more recent tablet devices.

DyKnow is a classroom learning system (CLS) developed specifically with Tablet PCs in mind. DyKnow assumes both the instructor and each student have a Tablet PC. DyKnow creates a shared white space between the students and the instructors. The central elements of DyKnow are the panel and the notebook, where a notebook is made up of panels much the way a PowerPoint™ presentation is made up of slides. DyKnow supports digital inking of each panel. Elements other than digital ink can be added to a panel as well, including images and text. During class, instructors start a "session" which students join, in the session students and instructors share a common notebook. The instructor's inking on a panel shows up on each student's notebook (unless the instructor uses a special "private" ink), but students can also apply digital ink to their copy of the shared notebook. At the end of a session, each student can save a copy of the notebook, which contains: any initial material that the instructor included as part of the notebook preparation, any “non-private” ink applied by the instructor, and any inking the student applied during the session. For a more thorough discussion of DyKnow see their website (dyknow.com).

In 2007 the engineering school at the University of Louisville required incoming engineering students to purchase a Tablet PC. At the same time the school acquired a DyKnow server, with licenses for 500 seats. All Engineering Fundamentals Department faculty members who taught mathematics courses moved to using Tablet PCs and Dyknow over a transition period of one year. Two faculty members with exceptionally strong computer skills quickly became expert DyKnow and Tablet PC users and provided training and support for other faculty members (a role they continue in today). The initial effort to incorporate DyKnow and Tablet PCs into *Engineering Analysis I, II* and *IIII* focused on adapting the delivery of existing course material to move from overhead projectors and chalkboard based lectures, to one delivered using Tablet PCs and DyKnow. To do this, DyKnow was used to share a set of instructor created skeleton notes during class lectures. Students would need to use their Tablet PC to connect to the DyKnow session during class to get the skeleton notes, but no class activity specifically required students to use their Tablet PC to take notes, though certainly they could. During class instructors would use DyKnow and/or OneNote™ (a Microsoft® Office application designed specifically for Tablet PCs) and digitally ink what had previously been written with chalk on a chalkboard. Hieb and Ralston [7] provide a detailed presentation of how DyKnow and Tablet PCs were used in this initial deployment.

All faculty teaching mathematics now fully embrace the use of Tablet PCs and DyKnow and confirm that the effort has been successful because the department took the approach of first simply using Tablet PCs and DyKnow to replicate established and familiar classroom practices. The creation of framework notes (or skeleton notes) was a logical progression for using Tablet PCs and DyKnow in a way that existing research indicated had positive impacts for teaching and learning. Only after replicating established practices did faculty feel comfortable leveraging the power of Tablet PCs and DyKnow for more advanced activities. This has happened, with several faculty now using active learning features available in DyKnow, specifically polling students through DyKnow™ during class and having students submit work via DyKnow during class.[8]

The impact of efforts to incorporate Tablet PCs and DyKnow into the engineering mathematics sequence have been measured through informal faculty interviews, class observations, several student surveys, and some analysis of grade distributions.

Faculty are uniformly excited about and prefer teaching with Tablet PCs, DyKno and OneNote. The following course presentation and delivery advantages were consistently reported by the majority of faculty in the department: students have the instructors’ annotations of prepared visuals; students must still actively take notes; faculty face students at all times, vastly improving eye contact; faculty time and energy is saved as there is no board erasing; students can play back instructor markup; the Tablet PCs and associated software make it very easy to use color, to create better figures, and to combine text, images and ink; finally, instructors have a complete copy of the actual lecture delivered each day. These benefits largely mirrored those mentioned in the literature, but there was an unforeseen and somewhat unexpected benefit. Because of the more efficient presentation (time savings) along with the fact that faculty now faced students, many instructors feel their interaction with students during problem solving is vastly improved.

From the student survey results, it was clear most students preferred faculty use of tablets and DyKnow to traditional chalkboard based lectures. Students and faculty both reported liking Tablet PCs but there was insufficient data to support general conclusions about their impact on teaching and learning. An initial comparison of grades from the first year DyKnow and Tablet PCs were used to the previous year showed the distribution of A and B grades to very similar. This is probably to be expected, as it would not be expect that measurable change in the more talented students' grades would occur. What instructors found encouraging was the slightly smaller percentage of D, F, and W grades and slightly larger percentage of C grades.[7] It was impossible to attribute that to the use of technology alone, but the results were encouraging, and there was no evidence of disenfranchising some students with the use of technology.

However, what became most apparent from the initial implementation study was that not all students used their tablets in class nor did it appear that most students appreciated the many note-taking benefits of the tablets. In a follow up study, Hieb et al. [9] examined this issue, discussing in detail the department's attempt to encourage students to embrace using their tablets for classroom note-taking in departmental as well as non-departmental classes. Based on both classroom observation and survey responses, a marked improvement in student use of tablets was achieved by requiring students to work problems on their tablets. Besides encouraging tablet use by explaining how to use tablets during class, it appears students needed repeated prompting to use their tablet during class. Students resist adopting the tablet for class note-taking if given the opportunity. But when encouraged strongly and repeatedly, the resistance faded for significant numbers of students, and many began to view their tablets as just another piece of educational equipment.[9]

3 MyMathLab (2010 – present)

MyMathLab is an on-line interactive learning system developed and maintained by textbook publishing company Pearson. MyMathLab includes an electronic copy of the course textbook, and additional types of media that provide course content such as videos, animations, presentation slides, and projects. MyMathLab also includes the MathXL engine which can present students with a problem similar to those in the exercise sets at the end of each section in the textbook. Most problems are algorithmic, meaning that each time the question is presented it is slightly different, using different numbers for example. The MathXL engine allows for traditional multiple choice type answers, but it is also able to parse mathematical expressions, allowing problems to ask students to enter: 1) exact numerical answers that use fractions, radicals, and symbols like π, 2) expressions such as the equation of the tangent line at a point, or even 3) other types of mathematical notation such as intervals and sets. MathXL grades students' answers and records these grades in an online gradebook. The MathXL engine also includes learning aids with each problem. Learning aids include: links to relevant sections in the textbook, "show me an example", and "help me solve this" which steps students through a solution. Instructors build problem sets by just selecting different problems using a graphical wizard in the web interface. Problems sets can be homework, quizzes, or tests. For homework problems, feedback about the correctness of an answer is immediate and when a problem is incorrect students can just ask for a similar problem to work. For quizzes and tests, students must complete the entire problem set before any feedback about correctness is give. Usually the quizzes and tests do not include the learning aids when they are presented to students. For a complete description of MyMathLab and all its features see (http://www.pearsonmylabandmastering.com/northamerica/mymathlab/index.html).

MyMathLab was piloted in *Engineering Analysis III* in the Fall of 2010. In the pilot program, written homework assignments, which were typically selected problems from the exercise sets at the end of each section in the textbook, were replaced with MyMathLab homework assignments. The text for the pilot was Thomas' Calculus, 11th edition. Student response was generally positive as was the faculty experience, and the department decided to adopt MyMathLab in all three courses: *Engineering Analysis I, II and III*.

Use of MyMathLab has gradually increased over the course of several years, beginning with all sections of *Engineering Analysis I, II and III* using MyMathLab for some of the assigned homework problems in each unit. Not all desired problems were available in MyMathLab, and for this reason, the initial adoption of MyMathLab, which started in the spring of 2011, moved 50%-75% of the assigned homework problems from written assignments to MyMathLab assignments to be completed and graded on-line. To address the issue of missing problems, two faculty members, assisted by some talented students, used the custom question builder tool in MyMathLab to extend the MyMathLab homework sets for each unit in *Engineering Analysis I, II and III* to include all the problems that had once been done as written assignments. Some creativity was required for certain problems, such as problems asking students to use the definition of derivative to compute$f'(x)$. By the fall 2012, 100% of the homework assignments for *Engineering Analysis I, II and III* was assigned and graded in MyMathLab. Faculty feel there is much to be gained from the algorithmic nature of the homework problems, the fact that students can't simply copy homework from another student, and the fact they can ask "help me solve this" or "show me a similar example" to get specific help. In these courses homework counts 5% of the course grade, meaning that only 5% of the course grade was coming from MyMathLab. The rest of the course grade came from quizzes, tests, and a comprehensive final exam, all of which were still being done using pencil and paper and graded by faculty and student graders.

As enrollment in the school of engineering has increased, grading all of the quizzes and tests that have historically been assigned in *Engineering Analysis I, II and III* is becoming increasingly difficult even with the help of student graders. With faculty and students satisfied with using MyMathLab for homework, the department has begun experimenting with using MyMathLab to replace a portion of the more formal assessments, specifically quizzes and tests. Currently, in most classes MyMathLab homework counts 5% of the course grade and between 15% to 40% of the course grade comes from MyMathLab quizzes and tests, with the remaining percentage of the course grade coming from pencil and paper ("higher stakes") assessments that are graded by faculty and student graders. The MyMathLab quizzes and tests are proctored and timed, using MyMathLab's password feature to prevent students from accessing the test in a non-proctored setting. Since the department has started using MyMathLab there has been an approximately 40% decrease in spending on student graders.

Faculty have expressed some concerns about having a greater portion of the course grade come from MyMathLab, and many students have expressed dissatisfaction with MyMathLab tests and quizzes. Students' primary complaint is the lack of partial credit and the fact that sometimes MyMathLab requires them to enter an answer in a specific form (for example use only positive exponents in expressing the answer). Students seem to think that the MyMathLab tests do not reflect their knowledge because they have to get the answer correct (and follow directions). Faculty have concerns both directions: students could enter the correct answer without knowing how to do the problem and students could make a simple mistake that causes their answer to be incorrect. To address these concerns and to evaluate MyMathLab, the authors compared the scores on MyMathLab quizzes and tests to the scores on the final exam. The results of that analysis are presented next.

In the fall of 2011, students in Engineering Analysis I took paper quizzes, using MyMathLab only for some of the homework problems. These paper quizzes were hand graded by student graders. In the fall of 2012, students in Engineering Analysis I took 13 quizzes, one each week, in MyMathLab. In the fall of 2013, students took a weekly test in MyMathLab, for a total of 13 MyMathLab tests. The MyMathLab quizzes and tests were scored by MyMathLab. Each year, students also took weekly paper tests and a comprehensive final exam. The final exam was hand graded by faculty and student graders. Linear regressions were done comparing the paper quiz average to the final exam score in 2011, MyMathLab quiz average to final exam score in 2012, MyMathLab test average to the final exam score in 2013, and the paper test average to the final exam score in 2013. The results of these regressions are shown in table 1. Paper exam scores had the highest R^2 value, which is expected since paper exams are most similar to the final exam. Paper quizzes did explain more variance in final exam score than did the MyMathLab assessments, although the 2013 MyMathLab tests had a higher R^2 value than did the 2012

MyMathLab quizzes, possibly because of improvements the instructors made in problem selection and creation. Figure 1 includes a scatter plot for each of the regressions performed. While paper exams still show the highest R^2 values, it is clear that the MyMathLab quizzes and tests are also good indicators of final exam performance. The lack of experience developing MyMathLab® quizzes and tests is a significant factor and it is possible that continued efforts to improve the MyMathLab quizzes and tests will lead to them having nearly equal predictive power as paper exams. Work is continuing to make the very best use of MyMathLab, most likely by requiring students to do all homework problems before attempting lower stakes assessments; then requiring those lower stakes assessments to be accomplished with a score above 75-80% before allowing students to take a paper assessment. In such a scenario, there would be more, lower stakes, MyMathLab assessments and fewer higher stakes paper exams than is done currently. Such an approach would maximize the utility of MyMathLab while providing students more opportunities to remediate their errors before taking a higher stakes paper exam.

Table 1. Results of linear regression analysis for Engineering Analysis I, fall of 2011, 2012, 2013.

Linear Regression	Adjusted R^2
2011: paper quiz average versus final exam score	71.0
2012: MML quiz average versus final exam score	60.6
2013: MML test average versus final exam score	66.0
2013: Paper tests average versus final exam score	82.4

4 Faculty produced videos (2013 – present)

In 2012, the department began investigating various course redesign strategies discussed in educational literature. This activity was motivated by the department's strategic plan to demonstrate effective teaching and learning by exploring and evaluating new approaches to engineering education. The six models for course redesign presented by the National Center for Academic Transformation (NCAT)[5] were the main focus of the department's investigation. The replacement model[10] was one of the redesigns that appealed most to department faculty. In the replacement model, the number of in-class meetings is reduced and online learning activities are used to replace that in-class time. Faculty were interested in providing some of what had traditionally been live lecture as video lectures that students could watch and even re-watch when they chose.

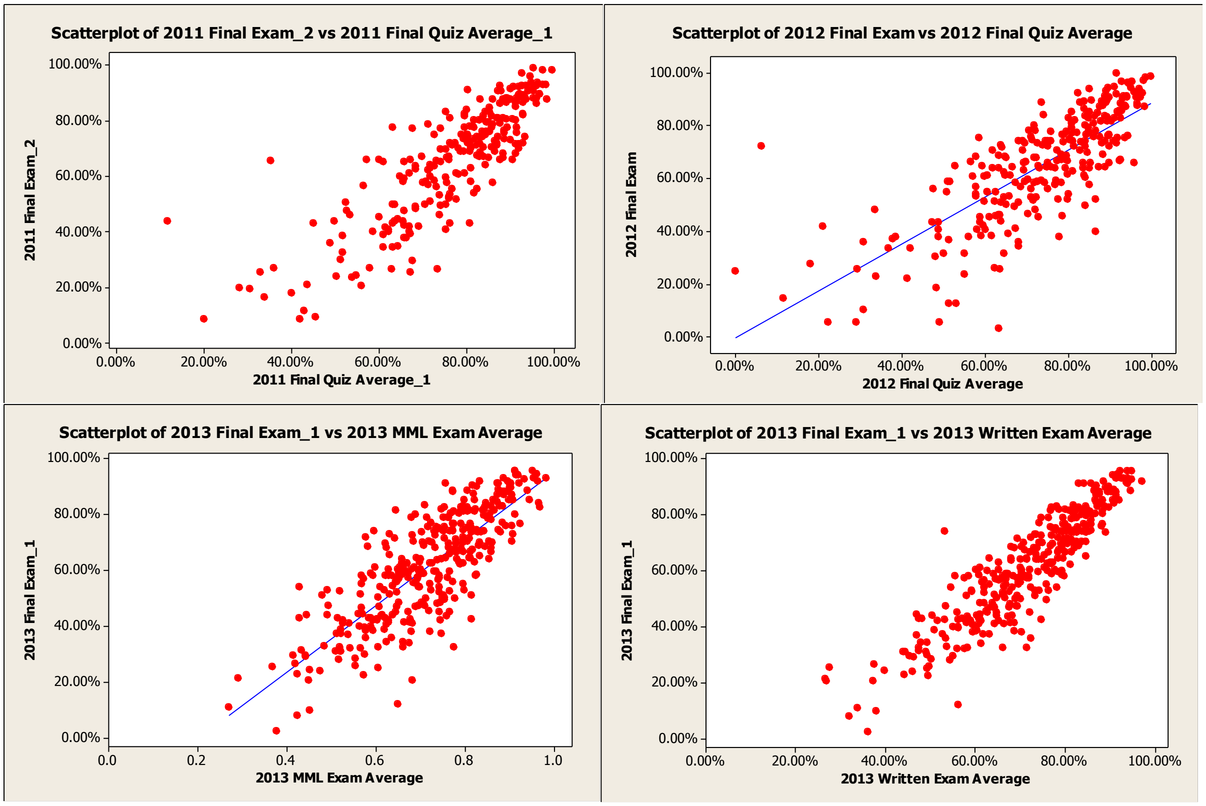

Figure 1. Scatter plots of the average of 2011 quizzes, 2012 MML quizzes, 2013 MML tests, and 2013 paper tests, versus the final exam score for the corresponding year; *Engineering Analysis I* in the fall of 2011, 2012, and 2013.

In fall 2013, approximately one third of the weekly lectures in *Engineering Analysis I* were replaced with video lectures. Prior to fall 2013, lectures were 50 minutes Wednesdays and Fridays and 45 minutes on Thursdays with a problem session on Mondays followed by a written exam on Tuesdays. In fall 2013, the Thursday lecture was removed; students left after a computer test in MyMathLab. The videos are accessible as assignments in MyMathLab, and while MyMathLab cannot determine if students have watched the video, MyMathLab scores whether students have opened the videos. This score is being counted as a small part of the students' grade. The department used engineering enhancements funds and other resources to outfit a small recording studio that includes digital cameras, a green screen, screen recording software, Wacom video screen, and video production software. Videos include screen captures of faculty working problems and faculty explaining material to the camera with visuals in the background. The videos closely replicate a traditional class lecture.

A one-question survey given to the students at the end of the semester asked if they would prefer a class lecture to the videos. Their response was that over 80% preferred the videos to lecture; many students wrote detailed explanations of enjoying the ability to replay the video while doing homework problems or reviewing a concept they didn't understand at first pass. A more detailed survey question given on course evaluations at the end of the semester asked students to rate the effectiveness of the videos in their learning on a 1-5 Likert scale with 1 – ineffective, 2- low, 3- average, 4- high, and 5- extremely effective. Eighty-eight percent of the respondents, (265/299) rated the videos as average, high, or extremely effective.

5 Discussion and Future Directions

The use of Tablet PCs and DyKnow has been a transformative experience for most faculty in the department. It has been difficult to identify unique and measureable ways this technology has impacted teaching and learning; however, most faculty would refuse to go back to chalkboards and overhead projectors, indicating that this technology may initially have had a greater impact on instructors than on students. Facing students all the time, not having to continually erase a chalkboard, and having a digital record of class notes are major advantages the adoption of this technology has had on the delivery of the engineering mathematics courses. Strongly felt to be a positive change by many faculty, but nearly impossible to measure, is the change in engagement between faculty and students that resulted from facing students, especially in large enrollment classes. The use of the more interactive features made possible by DyKnow is taking longer to integrate, and measuring its impact is equally difficult. Polling students during class with targeted multiple choice question can help instructors identify when a large number of students fail to comprehend a specific concept, but getting students to respond earnestly when no extrinsic rewards are attached to doing so is a challenge. Pioneering effective use of the interactive features in DyKnow will take much longer than the initial effort to replicate use of chalkboards and overheads with Tablet PCs and DyKnow.

The use of MyMathLab is now permanently a part of *Engineering Analysis I, II, and III*. Transitioning paper homework to MyMathLab went quickly, and there were few challenges. Scores on paper homework were always very high, by design, and similarly in MyMathLab homework scores are always nearly 100% since students can rework the problems as many times as necessary. The quality and timeliness of the formative feedback provided by MyMathLab homework greatly exceeds that of paper homework. Using MyMathLab for formal assessments (quizzes and tests) that count for a greater portion of students' final course grade has been more difficult, and there have been challenges. As the department experiments with MyMathLab quizzes and tests, initial analysis has shown that while not equivalent to paper assessments, MyMathLab quizzes and tests can be good predictors of performance on paper exams. The realized cost savings that have already occurred are encouraging faculty to identify effective ways to leverage MyMathLab to the greatest benefit for students. More faculty experience making and giving MyMathLab tests will most likely increase the fidelity of those assessments. It will not, however, address the fact that a number of students are reporting much greater test anxiety when taking MyMathLab tests than paper tests. The department is conducting a longitudinal study about motivation and learning strategies of incoming students that will hopefully help identify potential interventions that could help students reduce their test anxiety. However, utilizing the MyMathLab tests more for formative feedback in order to better prepare for paper tests and less for summative assessment should ease student anxiety and maximize the use of the technology.

The major ongoing challenge is determining the best way to assess the impact of these educational technologies on student learning and evaluate the overall effectiveness of the mathematics program. Most departmental faculty agree that the technologies have the potential to provide great benefit to student learning, but developing meaningful and specific measures of those benefits is challenging. When more than one technology has been incorporated simultaneously, it is very difficult to isolate cause and effect. The preliminary results mentioned in this paper are encouraging, but a more systematic way of measuring the quality of students' progression through the engineering mathematics sequence is needed.

Department faculty have initiated an assessment plan outlined as part of the department's strategic plan. Performance data in gateway courses in other departments and six year graduation rates on a cohort of students prior to any of the technology changes will be compared to those in the last five years. The department plans to then establish an ongoing program to track students throughout the engineering mathematics sequence and on to graduation. Faculty are interested to see if the time it takes to complete the engineering mathematics sequence, students' performance in core courses in their major discipline, and the graduation rate might better measure of the impact of educational technology adoptions on teaching and learning, especially if some other factors such as part-time employment, college preparedness, and enthusiasm for engineering as a career are controlled for. Developing the database, surveys, and infrastructure to gather and track this type of assessment information is the next critical step.

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