A CONTROLLED STUDY OF THE FLIPPED CLASSROOM WITH NUMERICAL METHODS FOR ENGINEERS

by

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Abstract

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Utah State University, 2013

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Recent advances in technology and ideology have unlocked entirely new directions for education research. Mounting pressure from increasing tuition costs and free, online course offerings are opening discussion and catalyzing change in the physical classroom. The flipped classroom is at the center of this discussion. The flipped classroom is a new pedagogical method, which employs asynchronous video lectures, practice problems as homework, and active, group-based problem-solving activities in the classroom. It represents a unique combination of learning theories once thought to be incompatible—active, problem-based learning activities founded upon constructivist schema and instructional lectures derived from direct instruction methods founded upon behaviorist principles. The primary reason for examining this teaching method is that it holds the promise of delivering the best from both worlds. A controlled study of a sophomore-level numerical methods course was conducted using video lectures and model-eliciting activities (MEAs) in one section (treatment) and traditional group lecture-based teaching in the other (comparison). This study compared knowledge-based outcomes on two dimensions: conceptual understanding and conventional problem-solving ability. Homework and unit exams were used to assess conventional problem-solving ability, while quizzes and a conceptual test were used to measure conceptual understanding. There was no difference between sections on conceptual understanding as measured by quizzes and concept test scores. The difference between average exam scores was also not significant. However, homework scores were significantly lower by 15.5 percentage points (out of 100), which was equivalent to an effect size of 0.70. This difference appears to be due to the fact that students in the MEA/video lecture section had a higher workload than students in the comparison section and consequently neglected to do some of the homework because it was not heavily weighted in the final course grade. A comparison of student evaluations across the sections of this course revealed that perceptions were significantly lower for the MEA/video lecture section on 3 items (out of 18). Based on student feedback, it is recommended that future implementations ensure tighter integration between MEAs and other required course assignments. This could involve using a higher number of shorter MEAs and more focus on the early introduction of MEAs to students.

(283 pages)

Public Abstract

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Recent advances in technology and new ways of using it have led to new possibilities for education research. Increasing tuition costs and free, online course offerings are two influences that have led researchers to re-consider the wisdom of conventional teaching methods and to consider alternatives. The flipped classroom is a new teaching method, which uses video lectures and practice problems as homework, while group-based problem-solving activities are used in the classroom. It combines aspects of two learning theories once thought to be incompatible—constructivism and behaviorism. Active, problem-based learning activities are based on the theories of constructivism, and direct instructional (video) lectures a based on behaviorist principles. The main reason for studying the flipped classroom is that it can potentially deliver the best from both worlds. A controlled study of students taking a second-year university course in numerical methods was conducted that used video lectures and model-eliciting activities (MEAs) in one section (treatment) and traditional group lecture-based teaching in the other (comparison). This study compared knowledge in two areas: conceptual understanding and conventional problem-solving ability. Homework and unit exams were used to measure conventional problem-solving ability, while quizzes and a conceptual test were used to measure conceptual understanding. No difference was found between the two sections on conceptual understanding (measured by quiz and concept test

scores). No difference in exam scores was found, either. However, homework scores were 15.5 percentage points (out of 100) lower for the comparison section, which is considered to be a large difference. This difference is probably due to the fact that students in the treatment section had a higher workload than students in the comparison section and did not complete some of the homework because it did not count very much toward the final course grade (5% out of 100%). Student responses to an opinion-based survey of the class were also compared. Students in the treatment section gave lower ratings for the course than students in the comparison section on 3 out of 18 items. The responses on the remaining 15 items were indistinguishable. Based on student comments about the course, it was recommended that future studies make sure there is tighter integration between in-class group activities (MEAs) and other assignments. This might involve shortening the length of group problems so that more problems can be solved in the same time. It should also include more guidance for students during early stages of group problem solving, and a better explanation of why solving MEAs will help students in their future careers.

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Chapter 1

Introduction

1.1 Motivation

There are currently two related movements that are combining to change the face of education. The first of these is a technological movement. This technological movement has enabled the amplification and duplication of information at an extremely low-cost. It started with the printing press in the 1400s, and has continued at an ever-increasing rate. The electronic telegraph came in the 1830s, wireless radio in the late 1800s and early 1900s, television in the 1920s, computers in the 1940s, the internet in the 1960s, and the world-wide web in the 1990s.

As these technologies have been adopted, the ideas that have been spread through their channels have enabled a second movement. Whereas the technological movement sought to overcome real physical barriers to the free and open flow of information, this ideological movement seeks to remove the artificial, man-made barriers. This is epitomized in the free-software movement, although this movement is certainly not limited to software.

A good example of this can be seen from the encyclopedia. Encyclopedia Britannica has been continuously published for nearly 250 years[1] (Encyclopaedia Britanica, 2012a). Although Encyclopedia Britannica content has existed digitally since 1981, it was not until the advent of Wikipedia in 2001 that open access to encyclopedic content became available to users worldwide. Access to Encyclopedia Britannica remains restricted to a limited number of paid subscribers (Encyclopaedia Britanica, 2012b), but access to Wikipedia is open, and the website receives over 2.7 billion US monthly page views. Thus, although the technology and digital content was available to enable free access to encyclopedic content, ideological

[1] Since 1768.

roadblocks prevented this from happening. It was not until these ideologies had been overcome that humanity was empowered to create what has become the world's largest, most up-to-date encyclopedia (Wikipedia, 2012).

In a similar way, the combined effects of these two movements on higher education are becoming evident. Educational research on instructional technology has made significant advances. Studies show that video lectures (slightly) outperform in-person lectures (Cohen, Ebeling, & Kulik, 1981), with interactive online videos doing even better[2] (McNeil, 1989; Zhang, Zhou, Briggs, & Nunamaker, 2006). Online homework can be just as effective as paper-and-pencil homework (Bonham, Deardorff, & Beichner, 2003; Fynewever, 2008), and carefully developed intelligent tutoring systems have been shown to be just as effective as human tutors (VanLehn, 2011). Despite these advancements, their adoption has been slow, as the development of good educational systems can be prohibitively expensive. However, the corresponding ideological movement is beginning to break down these financial barriers.

Ideologically, MIT took a significant step forward when it announced its OpenCourseWare (OCW) initiative in 2001 (MIT, 2012b). This opened access to information that had previously only been available to students who paid university tuition, which is over $40,000 per year at MIT (MIT, 2012a). Continuing this trend, MIT alum Salman Khan founded the Khan Academy in 2006, which has released a library of over 3200 videos and 350 practice exercises (Khan Academy, 2012). The stated mission of the Khan Academy is to provide "a free world-class education to anyone anywhere." In the past year, this movement has rapidly gained momentum. Inspired by Khan's efforts, Stanford professors Sebastian Thrun and Andrew Ng opened access to their online courses in Fall 2011. Thrun taught artificial intelligence with Peter Norvig, attracting over 160,000 students to their free online course. Subsequently, Thrun left the university and founded Udacity, which is now hosting 11 free courses (Udacity, 2012). With support from Stanford, Ng also started his own open online educational initiative, Coursera. Princeton, University of Pennsylvania, and University of Michigan have joined the Coursera partnership, which has expanded its offerings to 42 courses (Coursera, 2012). MIT has also upgraded its open educational initiative, and joined

[2] Effect size=0.5.

with Harvard in a $60 million dollar venture, edX (2012). EdX will "offer Harvard and MIT classes online for free."

While online education is improving, expanding, and becoming openly available for free, university tuition at brick-and-mortar schools is rapidly rising (National Center for Educational Statistics, 2012). Tuition in the University of California system has nearly tripled since 2000 (Gollan, 2011). Naturally, this tuition increase is not being received well by university students in California (Asimov, 2012). Likewise, students in Quebec are actively protesting planned tuition hikes (Delange, 2012). In resistance to planned tuition hikes, student protestors at Rutgers interrupted[3] a board meeting to make their voices heard (Heyboer, 2012). Adding fuel to the fire, results from a recent study by Gillen, Denhart, and Robe (2011) indicate that undergraduate student tuition is used to subsidize research. As a result, the natural question being asked by both students and educational institutions is exactly what students are getting for their money. This is applying a certain pressure on physical academic institutions to improve and enhance the in-person educational experience of their students.

Students are not the only ones demanding higher outcomes from educational institutions. There is also increasing pressure from accreditation institutions. In particular, the Accreditation Board for Engineering and Technology (ABET) specifies outcomes that university graduates in engineering and technology must meet for their programs to be accredited (ABET, 2013). Commonly referred to as outcomes 3a-k, these criteria include, "an ability to communicate effectively," and "an ability to identify, formulate, and solve engineering problems," as well as, "an ability to function on multidisciplinary teams." Many of these criterion are generally difficult to teach and assess effectively with informative lectures and closed form questions.

Problem-based learning methods, however, can be much more effective at achieving these goals. Felder and Brent (2003) survey research indicating that problem-based learning methods can be used to fulfill many ABET 3a-k outcomes. In engineering, model-eliciting activities (MEAs) have recently surfaced as a promising problem-based approach for fulfilling

[3] On June 20, 2012

these outcomes (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004). Model-eliciting activities are realistic, open-ended, client-driven engineering problems designed to foster students' mathematical modeling abilities (Diefes-Dux et al., 2004; Lesh & Doerr, 2003). Focused around six guiding principles, MEAs have the potential for improving student performance on all eleven ABET 3a-k outcomes (Diefes-Dux et al., 2004).

Adoption of MEAs and problem-based learning is hindered by the fact that the curriculum for engineering programs is already tightly packed. Cramming even more into these programs may seem impossible. Although computer technology is to blame for at least a portion of the uncomfortable situation in which educational institutions find themselves, it may also form a key part of the solution. Since the stone age, man has used tools to improve the effectiveness and efficiency of his efforts. In modern industry, this is accomplished by automating tasks that can be automated, and focusing human effort on those that cannot. Although group lectures have been sharply criticized in a portion of the educational literature (e.g., Paul, 1993), there seems to be little convincing evidence to support these criticisms. However, since video lectures can be as effective as in-person lectures at conveying basic information (Cohen et al., 1981; McNeil, 1989; Zhang et al., 2006), the wisdom of using student and instructor time for live lectures is questionable. Rather, pre-recorded lectures can be assigned to students as homework, leaving class time open for interactive learning activities—activities that cannot be automated or computerized. This is the key concept behind what is becoming the new buzzword in educational circles: the flipped classroom.

While the flipped classroom represents an exciting new topic in educational research, there is a lack of consensus on what exactly the flipped classroom is, and a corresponding lack of good research on its effectiveness. Thus, it is proposed that a specific version of the flipped classroom be studied that utilizes model-eliciting activities (MEAs) as the primary in-class activity, with video lectures and practice problems as assigned homework. There are three key features of this study that distinguish it from existing research:

- The use of Model-Eliciting activities as the primary in-class activity.

- Inclusion of a concurrent comparison group in the study.

- Objective comparison of student learning outcomes.

1.2 Purpose Statement

The purpose of this research is to compare the educational effectiveness of flipped classroom instruction consisting of model-eliciting activities and video lectures to traditional classroom instruction in a university-level introductory numerical methods course for engineers. Using a controlled research design, educational effectiveness will be evaluated along two dimensions: conventional problem-solving ability and conceptual understanding. Student perceptions will also be compared, which will help identify ways to improve on existing methods and evaluate the similarity of the current study with prior flipped classroom research.

1.3 Defining the Flipped Classroom

Perhaps the simplest definition of the *flipped*, (or *inverted*) classroom is given by Lage, Platt, and Treglia (2000). "Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (p. 32). This *flipping* is demonstrated in the first two rows of Table 1.1. Note that there are two other possible permutations of lecture and homework. Both may take place in class, or both may take place outside class. These might be referred to as boarding school and independent study, respectively. While this explanation captures the rationale for using the terminology *inverted* or *flipped*, it does not adequately represent the practice of what researchers are calling the flipped classroom. This definition would imply that the flipped classroom merely represents a re-ordering of classroom and at-home activities. In practice, however, this is not the case (Demetry, 2010; Foertsch, Moses, Strikwerda, & Litzkow, 2002; Lage et al., 2000; Toto & Nguyen, 2009; Warter-Perez & Dong, 2012; Zappe, Lieicht, Messner, Litzinger, & Lee, 2009).

Most research on the flipped classroom employs group-based interactive learning activities inside the classroom, citing student-centered learning theories based on the works of Piaget (1964/1967) and Vygotsky (1978). The exact nature of these activities varies widely

Table 1.1: Simplified Definition of the Flipped Classroom

Style	Inside class	Outside class
Traditional	Lectures	Practice exercises & problem solving
Flipped	Practice exercises & problem solving	Video lectures
De facto flipped	Questions & answers, group-based/open-ended problem-solving	Video lectures, closed-ended quizzes & practice exercises

between studies. Similarly, there is wide variation in what is being assigned as "homework." The flipped classroom label is more often assigned to courses that use activities made up of asynchronous web-based video lectures and closed-ended problems or quizzes. In many traditional courses, this represents all the instruction students ever get. Thus, the flipped classroom actually represents an expansion of the curriculum, rather than a mere re-arrangement of activities. A simplified depiction of this is shown in the last row of Table 1.1.

The flipped classroom is an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom. A graphic representation of this definition is shown in Figure 1.1.

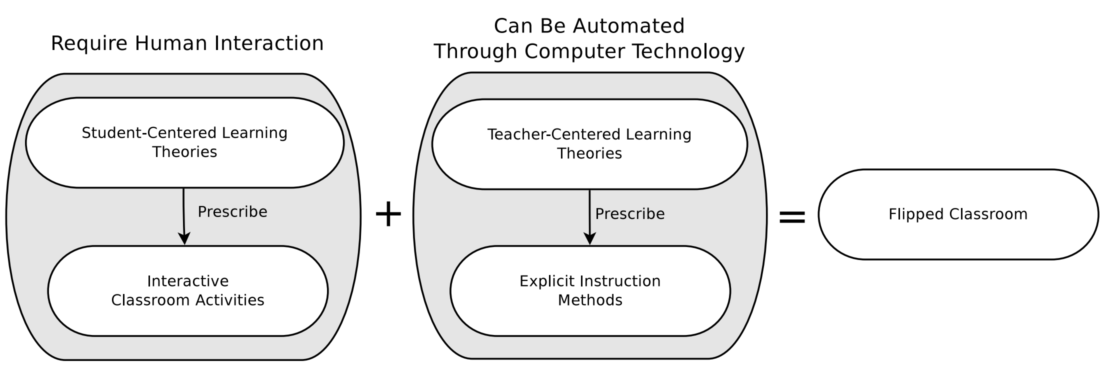

Fig. 1.1: Flipped classroom.

1.4 Educational Effectiveness and the Flipped Classroom

The Merriam-Webster Online dictionary defines education as, "the process of receiving or giving systematic instruction, especially at a school or university." Effectiveness is defined as "the degree to which something is successful in producing a desired result; success." Thus, educational effectiveness is the degree to which educational experiences [facilitated by a program and/or instructor(s)] are successful in producing the desired results.

This raises the question of what the *desired results* consist of. To address this question, two sources will be examined. First, the mission statement of the College of Engineering at Utah State University, which is: "To foster a diverse and creative learning environment that will empower students and faculty with the necessary knowledge and facilities to be international leaders in creating new technologies and services that will improve tomorrow's economy and environment."

Second, the Accreditation Board for Engineering and Technology (ABET), which sets forth several broad "outcomes 3a-k" that university programs should strive to achieve (ABET, 2013). These include

(a) an ability to apply knowledge of mathematics, science and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(e) an ability to identify, formulate and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

An essential first step is to select an educational method that shows promise in being able to achieve success on these criteria, which constitute the *desired results*. Several publications have already been mentioned that illustrate how MEAs (and other similar student-centered learning approaches) are uniquely positioned to help students attain these learning goals (e.g., Diefes-Dux et al., 2004; Felder & Brent, 2003).

One of the major challenges, however, is that progress on these outcomes is difficult to measure objectively. Further, a tradition has been established to almost exclusively examine student performance on solving pre-formulated closed-ended problems (problems with one known answer). Traditions such as these are not easily changed. In fact, one of the major criticisms of problem-based learning is that when it is implemented, knowledge outcomes tend to be lower than conventionally taught courses, even though skills are usually higher (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den Bossche, & Segers, 2005).

Because it represents a unique combination of both student-centered and conventional lecture-based teaching methods, the flipped classroom may perform better than purely problem-based approaches on knowledge outcomes, while still working toward broad learning goals that conventional teaching methods usually ignore. This statement represents the central motivating hypothesis of the present work. Successful evaluation of this theory will allow educators and future researchers to make more informed decisions that will hopefully lead to higher overall educational effectiveness.

1.4.1 Knowledge Outcomes of Student Learning

Two dimensions of objective student performance were identified, which will be used in this study as indicators of knowledge gained by students: conventional problem-solving ability, and conceptual understanding. Conventional problem-solving ability refers to how well students perform on closed-ended quantitative problem-solving tasks. An example of such problems within the context of the current work can be found at the end of each chapter in Chapra and Canale (2009). Conventional problem-solving ability is often contrasted with conceptual understanding (e.g., Mazur, 1997). As stated by Novak (1996), “concepts are packages of meaning; they capture regularities, patterns, or relationships among objects, events, and other concepts.” Thus, a concept is not unlike a *schema* as used by Piaget (1964/1967). The notion of conceptual understanding stems from the idea that knowledge is not merely a quantification of declarative facts that are stored in isolation from each other, but is also contained in the connections or relationships of facts and ideas to each other. Not surprisingly, conceptual understanding is measured by student responses to conceptual questions. Mazur (1997) contains numerous illustrative examples of that highlight the distinction between conventional and conceptual questions, but perhaps the best concrete example is the multiple-choice force concept inventory (Hestenes, Wells, & Swackhamer, 1992).

1.4.2 Student Perceptions

In addition, student perceptions of the course were also examined. Maintaining positive student perceptions is not to a stated goal or objective of the learning process, at least this is not specified as a desired outcome by ABET nor by the College of Engineering at Utah State University. Nevertheless, student perceptions of the learning process are regularly measured each semester by course evaluations. The results of the course evaluations were used to help establish whether the current study was similar in this regard to other studies of the flipped classroom, most of which focused exclusively on student perceptions.

Although it will have no bearing on the central focus of this research, which is to compare the educational effectiveness of the flipped classroom to the traditional classroom, a survey of student perceptions will help identify ways to improve the teaching and learning process.

1.5 Research Questions

Based on a thorough review of the literature, the primary hypothesis of this research is that a numerical methods course taught using the video lecture/MEA format will be as or more educationally effective than a traditional lecture-based course, on two dimensions: conventional problem-solving ability and conceptual understanding. Student perceptions between the two sections will also be compared. Based on prior research on the flipped classroom, it is anticipated that student perceptions in the section taught using the video lecture/MEA format will be equal or greater than those in the traditional lecture-based section. This leads to three specific research questions:

1. Will students in a numerical methods course taught using the video lecture/MEA format attain equal or higher conventional problem-solving performance than students in a traditional lecture-based course, as measured by student homework and exam scores?

2. Will students in a numerical methods course taught using the video lecture/MEA format attain equal or higher conceptual understanding than students in a traditional lecture-based course, as measured by conceptual quizzes and a concept test?

3. Will students in a numerical methods course taught using the video lecture/MEA format attain equal or higher opinions of the learning experience as students in a traditional lecture-based course, as measured by students' self-reported attitudes?

1.6 Dissertation Outline

The organization of the remainder of this dissertation is as follows: Chapter 2 provides a detailed review of the literature for each of the key areas of this research. That is, model-eliciting activities (within the broader psycho-educational context of student-centered learning theories), interactive video lectures (within the broader literature of computer-aided instruction), the flipped classroom (which combines the previous areas), and teaching numerical methods (which provides the context for the current study). Chapter 3 presents the details of the research design and methods used for this study. In particular, the analysis variables, measurement instruments, participants, and analysis procedures are described. The results of the present study are presented in Chapter 4, and a discussion is given of these results in Chapter 5. Finally, conclusions are summarized in Chapter 6, along with recommendations for future work.