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Probing the Inverted Classroom: A Study of Teaching and Learning Outcomes in Engineering and Mathematics

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EDUCAUSE LEARNING INITIATIVE

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SEI Case Study

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Snapshot

Institution: Harvey Mudd College, a private, four-year liberal arts college of science, math, and engineering, with an enrollment of about 800

Timetable: May 2012 to September 2016

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Flipped (or inverted) classrooms have started to become commonplace on university campuses. In a typical flipped course, students watch video lectures outside class, and classroom lectures are replaced with more active forms of student engagement. Despite the growing number of flipped courses, however, quantitative information on their effectiveness remains sparse. Studies currently available often lack measures of student learning, and many studies make “apples to oranges” comparisons of active learning in flipped classroom to traditional lecture courses with no active learning. Often, too, studies compare instruction in different semesters (or quarters) and with varying amounts of course content. More nuanced research is needed.

Active learning is a mode of instruction that focuses the responsibility of learning on learners, typically through meaningful in-class learning activities in place of traditional lectures, in which students passively receive information from instructors. Multiple studies have shown that active learning leads to better student outcomes.[1] Given that instructors in flipped classrooms are generally able to create more opportunities for students to apply or practice course material, we hypothesized that students in a flipped classroom would exhibit more learning compared to students in an unflipped class. We sought to compare an unflipped class that engages students in *some* active learning to a flipped class that creates more time for active learning and to look for measurable differences in student learning, attitude toward course material, and metacognitive skills.

1. Project Overview

1.1. Project Goals, Context, and Design

To investigate specific impacts of learning in flipped classrooms—and toward an overarching goal of improving student learning—we designed a multiyear study involving three instructors in engineering and mathematics. We investigated the following questions:

- Do students in inverted classrooms spend additional time actively working with instructors on meaningful tasks compared to students in control classrooms?

- Do students in inverted classrooms show higher learning gains?
- Do students in inverted classrooms demonstrate an increased ability to apply material in new situations?
- Do students in inverted classrooms demonstrate increased interest in and positive attitudes toward STEM fields?
- Do students in inverted classrooms demonstrate increased metacognitive gains?
- How satisfied are students and faculty with the inverted classroom model?

We hypothesized the following possible student-outcome differences for the treatment (flipped) sections:

- Higher learning gains, especially for underprepared students
- Increased ability to apply material in new situations (transfer)
- Increased interest in and positive attitudes toward STEM fields (affective gains)
- Increased awareness by students of how they learn and strategies that support their learning (metacognitive gains)

Our study design had three distinguishing dimensions:

- The use of direct assessment measures specific to each of our three courses/disciplines, in addition to indirect assessment measures
- Comparison of control and treatment sections offered simultaneously (to reduce student demographic variability), using the same instructor (to limit instructor bias)
- Direct assessment of learning gains and application, both within the course and in downstream courses, to determine whether learning gains persist

In the first two years of the study, we were careful to ensure that students in inverted and treatment sections were presented with the same set of tasks to complete, whether in class or outside class. For example, in the Engineering 82 course, students in the inverted section spend class time working on open-ended design tasks, whereas students in the control section have those same tasks assigned as homework. Exams and quizzes were identical in both control and treatment sections.

The project team comprises experienced instructors and educational researchers, including an external evaluator. The evaluator, Cobblestone Applied Research and Evaluation, Inc., was involved in the design of the study as well as data analysis. Our institutional research officer also assisted in data collection. Two campus units were involved: the engineering and mathematics departments. Funding from the National Science Foundation and the Harvey Mudd College Dean of Faculty Office helped support this study.

1.2. Data-Collection Methods

This study involves two different undergraduate classes at Harvey Mudd College (HMC): Mathematics 45 is a first-year course on ordinary differential equations and is taken by all students at HMC; Engineering 82 is a course on chemical and thermal processes that is taken by all engineering majors at HMC. The study was designed to compare students in inverted sections with those in control sections (i.e., sections taught in traditional formats) in both courses. Data were drawn from students and faculty in those courses. Treatment and control students completed the same measures (content assessments and student attitude surveys). Faculty members, who taught both the flipped and traditional sections, completed reflection papers related to their experiences.

Students were not randomly assigned to sections. Students signed up for sections of each class using the normal registration procedures, and because different sections of each class were offered at different times, scheduling constraints largely determined which section each student was in. However, the sections of each course were randomly assigned to be either treatment or control. In the case of Mathematics 45, because there were multiple instructors each teaching two sections with the same schedule, we made sure that each instructor had one treatment section and one control section and that not all of the treatment sections or control sections were at the same time so as to avoid time of day as a confounding variable.

Students in both sections of each course were administered a pretest and posttest attitude survey. The survey contained selected items from three established instruments: Research on the Integrated Science Curriculum (RISC), the Motivated Strategies for Learning Questionnaire (MSLQ), and the STEM Questionnaires developed by the STEM team at the Higher Education Research Institute (HERI). The pretest survey contained nine items from RISC; the remaining items were from the MSLQ. The posttest contained the same items but added additional survey items from the HERI questionnaires. The survey items used from the MSLQ contained constructs for self-efficacy for learning, metacognitive self-regulation, peer learning, and help seeking. The survey items used from the RISC and HERI were related to learning gains and attitudes about engagement, preparedness, and the course in general. Select survey items from the RISC and HERI were used to answer evaluation questions regarding interest in and attitudes about STEM.

In addition to the surveys, students completed content assessments related to the subject area.

Achievement Measures for Engineering 82

- The Thermodynamics Concept Inventory (TCI) is an online assessment created “to identify fundamental misconceptions about…thermodynamics in engineering students.”[2]
- The Chemical and Thermal Process Assessment (CTP) was developed specifically for this study and contains two complex problems for students. Students are assessed based on their ability to both identify and formulate problems and to apply knowledge and solve problems.
- The instructor also created Thermal Inquiry Projects (TIPs), in which students were asked to investigate two inquiries of their choice over the course of the semester. For each inquiry, students generated a report and miniposter. The main purpose of the TIP was to provide students with a project to get them thinking about thermodynamics beyond textbook problems. Students completed each project with a partner and were assessed based on performance in five domains: ability to communicate effectively (paper); ability to communicate effectively (poster); ability to identify and formulate engineering problems in thermodynamics; ability to apply knowledge and solve engineering problems in thermodynamics; and demonstration of an understanding of the impact of inquiry in a global, economic, environmental, and societal context.

Achievement Measures for Math 45

- The Math 45 pretest and posttest assessments were created by the instructors for the course. The pretest assessment consisted of five problems and was not factored into students’ final grades in the course.

- The posttest assessment used the same five problems from the pretest assessment plus four new problems and was used as the final assessment for the course. For the purposes of the study, only the five problems that were in both the pretest and posttest were used to compare the growth from the beginning to the end of the course for the inverted and traditional sections.

1.3. Data-Analysis Methods

With the help of the college's director for institutional research and effectiveness, select student demographic information was also collected, including student class level (i.e., freshman, sophomore, junior, senior), household income level, high school GPA, level of preparedness, and whether the student was a first-generation college student. These data were collected to help determine whether there were any differences in the constitution of the treatment and control groups. Analysis of these data showed that there were no unexpected differences in terms of subgroup participation. That is, each of the conditions (i.e., inverted and control) had statistically equivalent students from each of the subgroups analyzed. Overall, these findings suggest that the students in the inverted sections and the students in the control sections, while not randomly assigned, were well matched in terms of theoretically relevant demographic and background information.[3]

1.4. Findings

To date, preliminary data have been collected from the two courses over two years. Data for Engineering 82 came from the fall 2012 and fall 2013 semesters, and data for Mathematics 45 came from the spring 2013 and spring 2014 semesters. During the 2012–13 school year, 230 students consented to participate in the study. In 2013–14, 186 students consented. These data do not show any statistically significant differences in student learning or in affective or metacognitive gains between the treatment and control groups. There are no significant differences between students' pre- and postassessment scores, homework scores, or quiz scores. Students' written comments also had a typical mix of positive and negative comments about each format.

Based on student surveys, we know that most students who were required to watch videos watched them with full attention. Students also reported working outside class, either by themselves or with a mix of students from both inverted and traditional sections.

Though the lack of statistically significant differences appears to contradict our initial hypotheses, we were encouraged that at least we were not causing students measurable harm by flipping our instruction. A variety of reasons and contextual factors likely mitigate any potential positive effects of flipping. For example, all of the instructors are new to flipped instruction but are very familiar with more traditional active lectures. HMC cultivates a highly collaborative environment, and our students may not benefit appreciably from new opportunities to work together in class because they already do so in and outside class. Although we might have been able to work more closely with students in the flipped classroom, HMC students have many different ways of getting help with their coursework outside class. Students also dislike change, and the flipped classroom format is new to many of them.

1.5. Communication of Results

Although our study is not complete, we have communicated early results to select key stakeholders, including the college's trustees and faculty at both Harvey Mudd and at Pomona College (another of the Claremont Colleges). In addition, we have discussed results at several professional meetings, including the American Society of Engineering Education, the Joint Mathematics Meetings, and at a MathFest meeting of the Mathematical Association of America.

1.6. Influence on Campus Practices

Because of the preliminary nature of our results, there have not been any clear influences on campus practices to date.

2. Reflection on Design, Methodology, and Effectiveness

2.1. Project Design, Data Collection, and Analysis

Three years into our effort, we feel the study design has been effective. We have not had any significant problems with the assessment instruments or methods that were chosen. The design of the study has yielded some information, and we continue to adjust our instructional methods within the constraints of the study design to see if they might result in more significant differences in student outcomes.

We see this as "action research"[4] and also as a natural evolution of our teaching practices as instructors. For some of us, this is the first time that we have flipped our classes, and we are improving our teaching in the way that all teachers do. For example, during our second section of the flipped Engineering 82 class, we required students to ask questions on the videos and began each class by discussing the answers to those questions. We also asked each student group to explain their answers and processes for each problem completed in class. During our second round of the flipped Math 45 class, we incorporated more authentic mathematical modeling tasks (some based on current events, such as the chemical spill in Virginia) and more problems that directly address students' misconceptions.

2.2. Effectiveness and Influence on Campus Practices

It is still too early in our study to report final results or potential analyses of impact on effective teaching and learning practices. We hypothesized that increased student learning will arise primarily because of the additional time that students will have with instructors actively working on meaningful tasks in class. Our work may have implications for institutions seeking to push more instruction online, where instructor-mediated learning is limited. In addition, because this study involves two different disciplines, the results may be applicable across STEM fields.

Notes

1. Charles C. Bonwell and James A. Eison, *Active Learning: Creating Excitement in the Classroom*, ASHE-ERIC Higher Education Report No. 1 (Washington, DC: The George Washington University, School of Education and Human Development, 1991); Louis Deslauriers, Ellen Schelew, and Carl Wieman, "Improved Learning in a Large-Enrollment Physics Class," *Science* 332, no. 6031 (May 13, 2011): 862–864; and Michael Prince, "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education* 93, no. 3 (July 2004): 223–231.
2. See Thermal and Transport Concept Inventory.
3. Applications used for this project included SPSS (ANOVAs, t-tests, demographic chi-square, means, Pearson's r), Microsoft Excel (TCI analyses, TIP analyses, CTP analyses, qualitative analysis of Engineering 82 student reviews), and Microsoft Word (faculty course reflections). Statistical analysis methods used included performance on pre- and posttests, which were analyzed using a repeated measures analysis of variance (ANOVA), t-tests, mean (average) calculations, chi-square (demographic comparisons), and Pearson's r (for Math 45: correlations between video-watching practices and homework, final exam, and final course grade).
4. "Action Research," *Wikipedia*, retrieved January 6, 2015.