Probing the Flipped Classroom: A Controlled Study of Teaching and Learning Outcomes in Undergraduate Engineering and Mathematics

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

Introduction

A flipped classroom reverses the paradigm of traditional lecture courses by delivering lectures outside of class – by means such as videos or screencasts – and using class meeting time for instructor-mediated active learning. This format has the potential to transform STEM education by increasing student time spent on what research has demonstrated to be the most effective teaching techniques (i.e. active learning) without sacrificing material coverage or educational scaffolding. Many educators are beginning to invert their classrooms, but there is limited (or no) data on learning gains currently available. We are rigorously examining the impact of three instructors inverting two STEM courses, in engineering (thermodynamics) and mathematics (differential equations), by measuring student learning gains and attitudes towards the course material. Our expected measureable outcomes are:

1. Higher learning gains;
2. Increased ability to apply material in new situations (transfer);
3. Increased interest in and positive attitudes towards STEM fields (affective gains); and
4. Increased awareness by students of how they learn and strategies that support their learning (metacognitive gains).

We hypothesize 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. If our hypotheses prove true, that will have implications for institutions that are 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.

The inverted classroom model (and a traditional classroom model) was implemented at Harvey Mudd College during the 2013-14 academic year in two courses: Engineering 82 (a thermodynamics course) and Math 45 (introductory differential equations). In 2014, the National Science Foundation (NSF) provided support for this research endeavor, which will continue through the 2015-16 academic year.

Using a variety of implementation and outcome measures (e.g., pre and post assessments of student surveys; content assessments; homework and course grades) the evaluation assessed the extent to which the inverted classroom model impacted students in three primary areas: Academic Learning Gains; Transfer of Knowledge; Metacognitive Gains. In addition, the evaluation also included student satisfaction and faculty experiences.

Method

Design

The quasi-experimental study design was developed to compare students from inverted sections with those in control sections (i.e., traditional course model). Treatment and control students completed the same measures (e.g., content assessments and student attitude surveys) and faculty members, who taught in both conditions, also completed reflection papers related to their experiences. The guiding research questions for the study and an overview of the assessment measures are shown in Table 1 below (more details on assessment measures are included in a subsequent section of this paper).

Table 1. Evaluation Questions and Outcome Measures

Evaluation Question	**Measure**	
	Engineering 82	**Math 45**
Implementation		
1. Do students in inverted classrooms spend additional time actively working with instructors on meaningful tasks in comparison to those students in control classrooms?	Student survey	
2. Do students in inverted classrooms actively participate and prepare for class through the videos and other materials?	Student survey	
Outcomes		
3. Do students in inverted classrooms, especially under-prepared students, show higher learning gains as compared to students in traditional classrooms?	Thermal Concept Inventory (TCI); Chemical and Thermal Process Assessment (CTP)	Pre/post math content assessment
4. Do students in inverted classrooms demonstrate an increased ability to apply material in new situations as compared to students in traditional classrooms?	Thermal Inquiry Projects (TIP)	Selected questions from the pre/post math content assessment
5. Do students in inverted classrooms demonstrate increased metacognitive gains as compared to students in traditional classrooms?	Selected items from Motivated Strategies for Learning Questionnaire (MSLQ) and Metacognitive Awareness Scale (MAS) on student surveys	
6. What are faculty experiences when teaching inverted course sections?	Faculty Reflection Papers	

Course Format

Engineering 82 met twice a week in 75-minute sessions. The control section was composed of 10-15 minute mini-lectures punctuated by conceptual and long form (calculation required) iClicker questions. Most students worked on the longer iClicker questions in informal, self-selected groups of 2-3. The inverted section meetings began with a 5-10 minute review of the video materials and 5-10 minutes answering questions asked in minute papers from the previous class meeting. The students then worked in self-selected groups of 3-5 on one problem extracted from the control section's homework assignment, while the instructor circulated to answer questions and intervene when students were reinforcing each other's misconceptions. After completing the problem, each team explained their solutions and reasoning to the instructor, and the instructor attempted to clear up any remaining misconceptions.

Math 45 met three times a week in 50-minute sessions. The control section was mainly a traditional lecture format, with many pauses, example problems, and "check-in" problems to check on student understanding. In the flipped class, the first five minutes were usually spent answering questions about the video that was watched. Then, the instructors would ask students to work on homework questions that were directly related to the videos. Sometimes students worked in groups; sometimes they worked individually. The instructors walked around the room to check on student understanding and ask and answer questions.

For both Engineering 82 and Math 45, all PowerPoint slides and tablet writing shown in the control section were contained in the video watched by the inverted section. For both courses, all students completed the same problems that students in the control section completed as homework. In Engineering 82, students in the inverted section completed specified problems during class meeting time (and turned them in at the end of class) and turned others in as homework. In Math 45, students in the inverted section used in-class time to work on any problems from the homework assignment and turned in all of their work as homework. As a final note, students in both sections of Math 45 had access to the videos; only students in the inverted section of Engineering 82 were allowed access to the videos.

Measures

Students in both sections of each course were administered a pretest and posttest attitude survey. The pretest survey contained a total of 28 selected items from established instruments including from the Research on the Integrated Science Curriculum (RISC), Motivated Strategies for Learning Questionnaire (MSLQ), Metacognitive Awareness Scale (Schraw & Dennison), and the STEM Questionnaires developed by the STEM team at the Higher Education Research Institute (HERI). A factor analysis was conducted on the pretest survey questions to determine which questions were most appropriate to represent the various constructs of interest including self-efficacy for learning, metacognitive self-regulation, peer learning, and help seeking behavior. Based on these data, a truncated scale was administered to students at posttest. Items used as part of the posttest include 14 items from the MSLQ and 4 items from the Metacognitive Awareness Scale (MAS). The posttest also included additional items from the HERI questionnaire as well as course-specific questions. Data from specific survey constructs were used to answer evaluation questions related to metacognition and attitudes. In addition to the surveys, students completed content assessments (described below) related to the subject area.

Engineering 82 Achievement Measures

- The **Thermal Concept Inventory** (TCI) is an online assessment created "to identify fundamental misconceptions about … thermodynamics in engineering students" (http://www.thermalinventory.com/). The TCI has a total of 24 points possible and contains five sub-measures including: Entropy and Second Law (8 points possible), Internal Energy vs. Enthalpy (4 points possible), Steady State vs. Equilibrium (4 points possible), Ideal Gas Law (4 points possible), and Conservation of Mass (4 points possible). The TCI was used to assess learning gains from pretest to posttest (Evaluation Question 3).
- The **Chemical and Thermal Process Assessment** (CTP) contains two complex problems for students. Each problem is graded in two areas: *Identify and Formulate*

Problem and *Apply Knowledge and Solve Problem.* Each of the two areas had a total of five points possible. The CTP was used to assess learning gains from pretest to posttest (Evaluation Question 3).

- For the **Thermal Inquiry Project** (TIP), students were given the assignment to investigate two "inquiries" of their choice over the course of the semester. For each inquiry, students generated a pretest report and mini-poster and a posttest report and mini-poster. The main purpose of the projects was to provide students with a project to get them "thinking about thermodynamics beyond the textbook" (TIP student handout). Each project was done with a partner and projects had a total of five points possible for each of 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. A total weighted score was also calculated (i.e., Ability to Identify and Formulate Engineering Problems in Thermodynamics: weighted x 3; Ability to Apply Knowledge and Solve Engineering Problems in Thermodynamics: weighted x 5) for a total of 55 points possible. TIPs were used to assess if students could apply material to new situations (Evaluation Question 4).

Math 45 Achievement Measures

- The **Math 45 pretest and posttest assessments** were created by the Mathematics Department. The pretest assessment consisted of five problems worth 10 points each for a total of 50 points and was not factored into students' final grades in the course. The posttest assessment used the same five problems from the pretest assessment plus an additional four new problems and was used as the final assessment for the course. For the purposes of the evaluation, only the five problems that were used for the pretest and posttest assessments were used to compare the growth from the beginning to the end of the course for the inverted and traditional sections (Evaluation Question 3). In addition, the faculty identified a subset of questions from the pretest and posttest that could be used to assess if students could apply material to new situations. We created a composite score to address this for Evaluation Question 4.
- There were five quizzes that were administered throughout the course. We analyzed the course's **quiz composite score** which was the average of all the quiz scores with the lowest score dropped. The composite score is reported as percent correct (i.e., 0% to 100%). The quiz composite score was used to assess learning gains from pretest to posttest (Evaluation Question 3).
- The **homework composite score** was calculated in the same manner as the quiz composite score. There were nine homework assignments and a final homework project that made up this composite score. The composite score was calculated by taking the average of the homework and project scores with the lowest homework score dropped. The composite score is reported as percent correct (i.e., 0% to 100%). The homework composite score was used to assess learning gains from pretest to posttest (Evaluation Question 3).

Participants

In Year 1, a total of 230 students (117 treatment; 113 control) completed the student survey for both courses. Engineering 82 had 31 students in the inverted section and 23 students in the control section. Math 45 had a total of 86 students in the inverted sections and 90 students in the control sections. In Year 2, a total of 186 students in both courses (87 treatment; 99 control) comprise the overall sample, though sample sizes varied for each specific measure (see **Table 2**). Engineering 82 had a total of 20 students in the inverted section and 28 students in the control section. Math 45 had a total of 73 students in the inverted sections and 76 students in the control sections. As shown below, however, not all students completed or received scores for each assessment.

Table 2. Year 2 Sample Size per Assessment (n = 186)

Course	**Survey**	**Content Assessments**			
Engineering	Student Survey (pre & post)	Chemical and Thermal Processes (pre & post)	Thermal Concept Inventory (pre & post)	Thermodynamic Inquiry Project (pre only)	Thermodynamic Inquiry Project (post only)
	37	40	30	39	48
Math	Student Survey (pre & post)	Course Assessment (pre and post)	Homework Composite Score	Quiz Composite Score	Transfer Questions
	79	143	141	145	143

All participants' demographic characteristics were analyzed each year of the study. Analyses showed that the groups were equivalent at pretest. Other demographic information analyzed include: class level (i.e., freshman, sophomore, junior, senior) and total cumulative hours. These analyses also showed no unexpected differences between inverted sections and control sections in terms of sub-group participation. That is, each of the conditions (i.e., inverted and control) had statistically equivalent students from each of the sub-groups 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.

Results

The following provides results for the second year of the study except where noted (for results from the first year, see Lape et. al. 2014), organized according to each research question. Given the differences between the Engineering and Mathematics content, data are provided for each discipline separately.

Research Question 1: Do students in inverted classrooms spend additional time actively working with instructors on meaningful tasks in comparison to those students in control classrooms?

Student surveys were used to ascertain measures of implementation for both the inverted and traditional course sections. Specifically, students in both formats were asked to describe any perceived differences between those that were in the inverted sections compared to those in the traditional sections on the posttest. A qualitative analysis of student responses ranged in level of differences or indicated that there were no perceived differences at all. Specially, student differences were in terms of workload, content understanding, and differing levels of information provided.

> *"It seemed the flipped had less of a grasp on the material. All they really knew how to do were the homework problems, but if you asked them a concept from something off the lectures that wasn't on the homework, they usually couldn't answer"*
>
> ***-Traditional Format Student***

Some students in the traditional section noted that students in the inverted section were more informed and "*already knew how to do some of the problems because they did them in class*". In addition, some students in the traditional classes indicated that they would have liked to have the same opportunity to get a head start on homework that they perceived the Math 45 students to have. Conversely, others indicated that they had to clarify the videos and other content for students in the inverted section. However, traditional students noted that inverted students often complained. In an exemplar quote one student noted, "*The people in the flipped section were usually more annoyed about their homework, and also had more of it done*." Another student commented, "*The flipped sections seemed to not like the flipped sections*."

Furthermore, students in the inverted section indicated that students in the traditional section believed they had more homework but did not take into consideration the time spent watching videos outside the classroom. One student indicated, "*The non-flipped sections had more homework problems, but the flipped sections had to devote more time to the videos, so the time spent in this class seemed relatively even between the two sections*." Other inverted students indicated that the traditional section in fact did have more stress in regards to homework. Specifically, one student indicated, "*There seemed to be less stress because the not flipped class had to do a lot more work outside of class than we did*."

> *"The students in the flipped section understood more about how to solve problems while the students from the non-flipped section understood the background of the concepts better."*
>
> ***-Inverted Format Student***

In addition to workload, students in the traditional section indicated that students in the inverted section had more tips and information. When noting differences, a student in the inverted section admitted, "*The students in the flipped sections got hints that the students in the non-flipped sections did not have*." Similarly, another inverted student indicated, "*… sometimes it seemed that the non-flipped class didn't have all the same information*".

Overall, there was a polarized view from students regarding their opinions about the inverted classroom design. In addition, students in the traditional format often reported that students in the inverted section had a head start on the homework but did not fully understand the content along with having frustration for the study design. This was similar to the feedback provided in the previous year.

Student Participation and Preparation

Research Question 2: Do students in inverted classrooms actively participate and prepare for class through the videos and other materials?

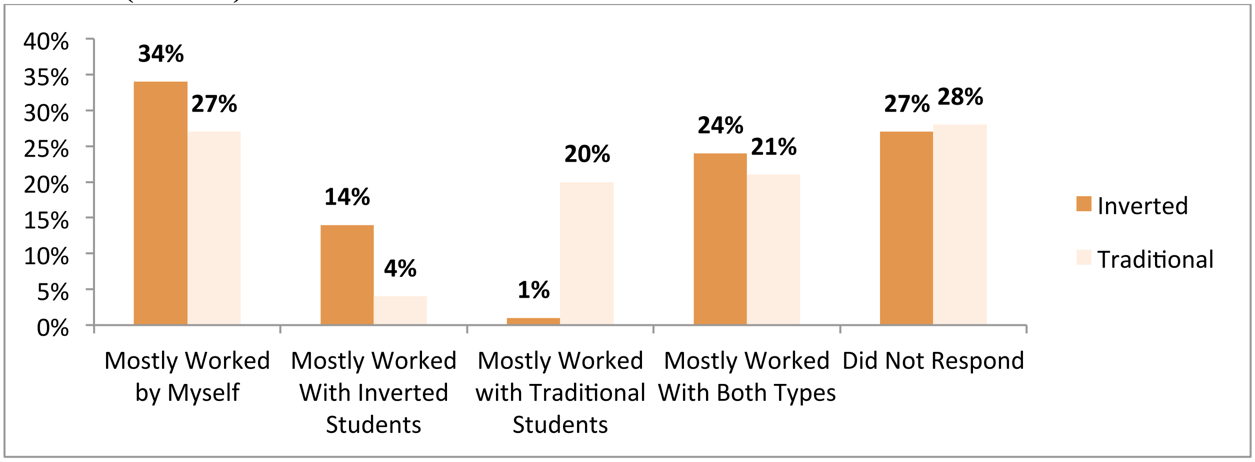
The posttest student survey administered to both Engineering 82 and Math 45 students requested students to report on several variables of interest regarding the lecture videos. First, students indicated their experience they most often had while watching the videos in relation to the outside distractions experienced during viewing. A total of 69 students from the inverted sections of both the Engineering 82 and Math 45 courses responded to this question. As expected, most students (64%) reported watching the videos with full attention and no distractions or almost full attention with minor distractions; however, there was a small group of students (7%) that reportedly watched videos with slight or minimal attention. An analysis on the distractions while video lectures in Math 45 shows a non-significant correlation between viewing habits and performance on the quiz composite, $r = -.132$, $n = 48$, $p = .372$; and the final exam, $r = -.018$, $n = 48$, $p = .902$. This finding does not indicate that a decreased amount of distraction experienced while watching the lecture videos predicted significantly higher quiz composite or final exam scores.

Additionally, all students were asked on the posttest survey to report if they:

- Studied alone
- Mostly studied with other students who attended an inverted section
- Mostly studied with other students who attended a traditional section
- Or mostly with students who were in both types of sections

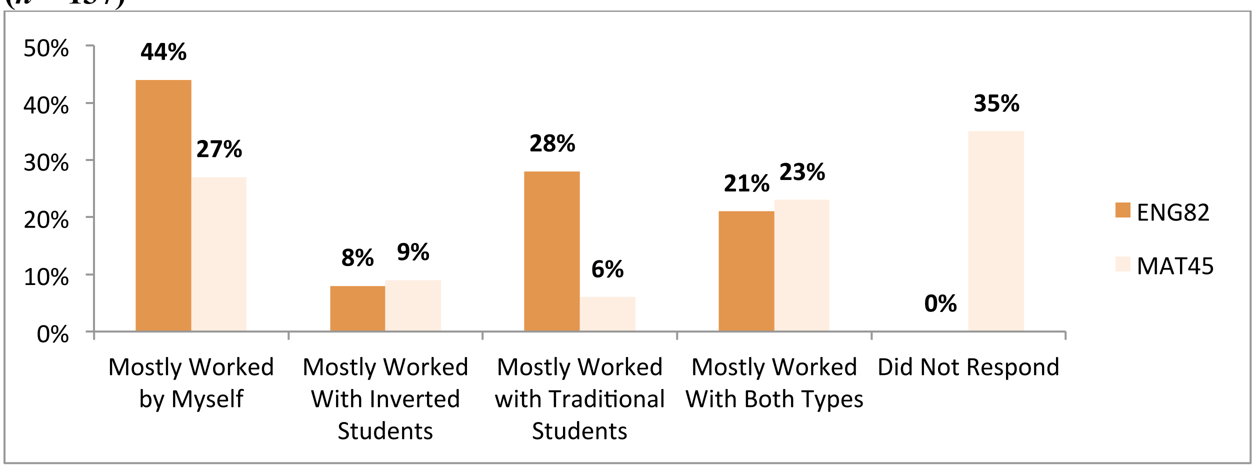
Across course types, students mainly reported working either by themselves or with a mix of students from both types of sections. Slightly more students in the inverted class reported working alone compared to students in the traditional section, but this difference was not statistically significant (see **Figure 1**).

Figure 1. Frequency of Homework and Study Habits by Inverted or Traditional for Both Courses (*n* = 137)



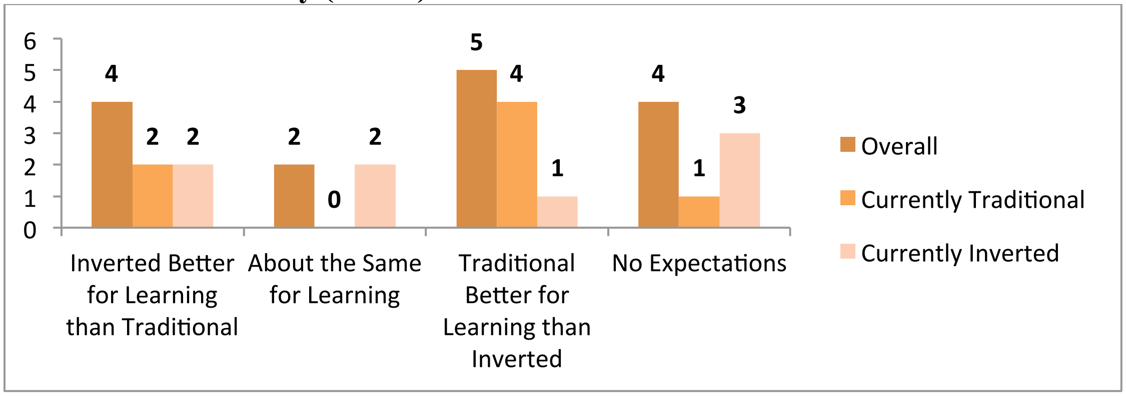
Additionally, a higher percentage of students in Engineering 82 reported working alone compared to the percentage of students in Math 45 who reported this (see **Figure 2**).

Figure 2. Frequency of Homework and Study Habits by Course Type for Both Conditions (*n* = 137)



Students who had been previously enrolled in an inverted course were asked about their attitudes and opinions on the inverted classroom in comparison to a traditional classroom format. None of the Math 45 students had previously taken an inverted course. Of the respondents who had, eight students had previously taken an inverted course at Harvey Mudd College and were enrolled in the traditional section of Engineering 82, while seven students had previously taken an inverted course at Harvey Mudd College and were enrolled in the inverted section of Engineering 82. When comparing the format of an inverted classroom to a traditional format, respondents had mixed results (see **Figure 3**). Overall, slightly more students had expected the traditional classroom format would be a better fit for their learning than the inverted classroom format.

Figure 3. Frequency of Respondent Expectations Who Had Experienced Inverted Classrooms Previously (n = 15)



However, when looking at responses by course format, students who had previously taken a flipped course and were currently in the traditional section (n = 8) reported more frequently they expected the traditional classroom to be better for their learning, indicating that this expectation may have been shaped by their previous inverted classroom experience.

Student Learning Gains

Do students in inverted classrooms show higher learning gains as compared to students in traditional classrooms?

Engineering 82: Learning Gains from Thermal Concept Inventory

A total of 30 students completed both a pretest and a posttest Thermal Concept Inventory (TCI) with 19 students in the traditional section and 11 students in the inverted section. *Students in the traditional section had significantly higher posttest Total Scores and scores on the Entropy and Second Law sub-measure as compared to their pretest scores*. However, *all students, regardless of the section, did not show significant gains from pretest to posttest for the remaining sub-measures*: Internal Energy vs. Enthalpy, Steady State vs. Equilibrium, Ideal Gas Law, and Conservation of Mass. Notably, students in the inverted section showed lower scores on the posttest for the sub-measures of Ideal Gas Law and Conservation of Mass (see **Tables 4** and 5).

Table 3. Thermal Concept Inventory Growth from Pretest to Posttest (n = 30)

Measure	**Traditional**			**Inverted**		
	t	df	p value	t	df	p value
TCI Total Score	4.61	18	**.000**	.384	10	.709
Entropy and Second Law	6.73	18	**.000**	1.72	10	.116
Internal Energy vs. Enthalpy	1.57	18	.134	.350	10	.733
Steady State vs. Equilibrium	1.53	18	.144	.153	10	.882
Ideal Gas Law	1.57	18	.134	-.971	10	.355
Conservation of Mass	1.29	18	.215	-1.15	10	.277

To determine if there were differences between students in the traditional section and the inverted section, the TCI was analyzed using a Repeated Measures ANOVA given that a pretest and posttest were administered to students in both sections of the course. *Results indicated that* *students in the traditional section of the course had a greater overall increase from pretest to posttest for the TCI total score than students in the inverted section.* However, for each of the sub-measures, there were no statistically significant differences in the rate of change between pretest and posttest when comparing the traditional section and the inverted section. *Thus, students mostly performed comparably on the TCI regardless of which section they were placed.* **Table 4** shows the details of the analyses. These data do need to be interpreted with caution given the small sample size and disproportionate sample sizes for the inverted and traditional course sections.

Table 4. Thermal Concept Inventory: Repeated Measures ANOVA Results (*n* = 30)

Measure	**Traditional (*n* = 19)**		**Inverted (*n* = 11)**		***df***	***F***	***p* value**
	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
TCI Total Score	12.42 (2.71)	16.84 (2.65)	12.64 (2.25)	13.27 (4.03)	1, 28	4.53	**.042**
Entropy and Second Law	3.79 (1.44)	6.16 (.96)	3.82 (1.60)	5.27 (2.37)	1, 28	1.35	.256
Internal Energy vs. Enthalpy	1.84 (.90)	2.26 (1.00)	1.72 (1.19)	1.91 (1.14)	1, 28	0.21	.654
Steady State vs. Equilibrium	2.58 (1.61)	3.37 (1.07)	2.55 (1.21)	2.64 (1.29)	1, 28	0.73	.400
Ideal Gas Law	2.40 (1.02)	2.84 (0.69)	2.18 (1.17)	1.64 (1.03)	1, 28	3.07	.091
Conservation of Mass	1.79 (1.23)	2.21 (1.03)	2.36 (1.21)	1.82 (.75)	1, 28	2.97	.096

Engineering 82: Learning Gains from Chemical and Thermal Process Assessment

A total of 40 students, 25 in the traditional section and 15 in the inverted section, completed both a pretest and a posttest for both Chemical and Thermal Process (CTP) assessment problems. *Students in both traditional and inverted sections showed significant gains from pretest to posttest on the CTP*. These gains were consistent for each sub-measure (i.e., Identify and Formulate Problem, Apply Knowledge and Solve Problem) for both problems on the CTP as well as the total scores for both of the two problems (see **Table 5**).

Table 5. Chemical and Thermal Process Growth from Pretest to Posttest (*n* = 40)

Measure	**Traditional**			**Inverted**		
	t	*df*	*p* value	*t*	*df*	*p* value
Problem 1: Identify & formulate problem	22.17	24	< .001	22.14	14	< .001
Problem 2: Identify & formulate problem	21.42	24	< .001	14.77	14	< .001
Total: Identify & formulate problems	**25.43**	**24**	**< .001**	**20.57**	**14**	**< .001**
Problem 1: Apply knowledge & solve problem	20.65	24	< .001	23.93	14	< .001
Problem 2: Apply knowledge & solve	19.93	24	< .001	20.51	14	< .001

problem						
Total: Apply knowledge & solve problems	**23.42**	**24**	**< .001**	**24.39**	**14**	**< .001**

To determine if there were differences between students in the traditional section and the inverted section, the CTP was analyzed using a Repeated Measures ANOVA. *Results indicated that there were no differences in the rate of change between pretest and posttest when comparing the traditional section and the inverted section after students completed the CTP*. Thus, students performed comparably on the CTP regardless of which section they were placed (see **Table 6**). Problem 2: Apply Knowledge and Solve Problem was the only item that approached significance.

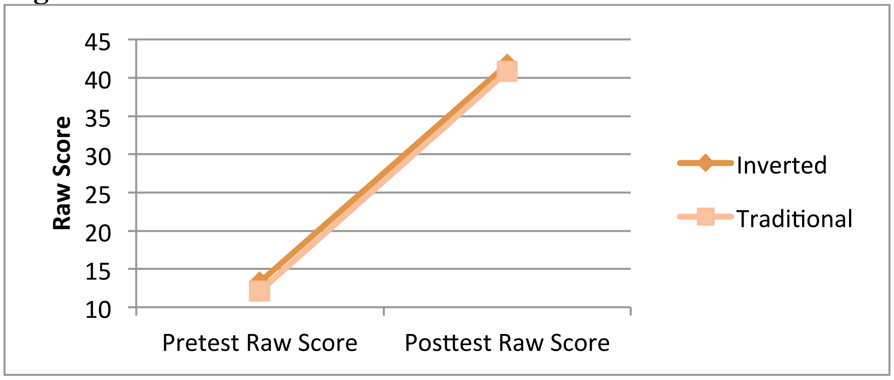
Table 6. Chemical and Thermal Process: Repeated Measures ANOVA Results (*n* = 40)

Measure	**Traditional**		**Inverted**		***df***	***F***	***p* value**
	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
Problem 1: Identify & formulate problem	0.36 (.81)	4.78 (.54)	.20 (.41)	4.77 (.53)	1, 38	0.234	.631
Problem 2: Identify & formulate problem	0.72 (.74)	4.34 (.70)	0.80 (.77)	4.60 (.60)	1, 38	0.372	.546
Total: Identify & formulate problems	1.08 (1.32)	9.12 (1.07)	1.00 (1.00)	9.37 (1.60)	1, 38	0.401	.530
Problem 1: Apply knowledge & solve problem	0.28 (.74)	4.30 (.56)	0.00 (.00)	4.40 (.71)	1, 38	1.72	.197
Problem 2: Apply knowledge & solve problem	0.52 (.71)	3.86 (.68)	.33 (.49)	4.17 (.67)	1, 38	3.58	.066
Total: Apply knowledge & solve problems	0.80 (1.26)	8.16 (1.10)	.33 (.49)	8.57 (1.28)	1, 38	3.27	.079

Math 45: Learning Gains from Pretest and Posttest Assessments

Analysis of the Math 45 pretest and posttest assessments showed no differences between the inverted sections and traditional sections at pretest [inverted M = 13.22, control M = 12.06; t(141) = -0.73, ns] and posttest [inverted M = 41.73, control M = 40.82; t(143) = -0.85, ns]. The data show that students in the inverted section both started and ended the course with slightly higher scores than students in the traditional section, though these differences were not statistically significant. The data show that both sections exhibited equal rates of change between the pretest and posttest, $F(1, 141) = 0.61$, $p = .805$. This effect is depicted in **Figure 4.**

Figure 4. Math 45 Pretest and Posttest Scores: Inverted vs. Traditional



Math 45: Learning Gains from Homework Composite Results

The homework composite scores showed no significant differences between the traditional sections and inverted sections [inverted M = 87.29, control M = 85.04; t(143) = -1.72, ns]. Of the students who scored 80 or less on the homework, an approximately equal number were in each section (16 in the traditional section and 12 in the inverted section) of Math 45. This is notable because the previous year's analysis indicated that students in the inverted section were more likely to score 80 or lower on the homework, which suggested that participation in the inverted section may impair performance on the homework assignments for a certain sub-group of students. However, given the lack of this discrepancy, it is possible that class type alone does not have a significant effect on homework scores. Also, we assume that students in the inverted sections were working more collaboratively on the homework in class which may contribute to the "clumping" of homework composite scores as opposed to the normal distribution of scores seen in the traditional sections.

Math 45: Learning Gains from Quiz Composite Results

The quiz composite scores showed no significant differences between the traditional sections and inverted sections [inverted M = 75.94, control M = 75.66; t(143) = -.114, ns]. Further analysis of the data did not show any systematic differences between the students in the inverted and traditional sections.

Student Learning Gains Summary

Overall, students in the inverted sections and students in the traditional sections performed equivalently in their courses. There were some instances where student scores showed trends that supported the inverted classroom model and trends that supported the traditional model. For example, on the TCI assessment (Engineering 82), students in the traditional section had significantly higher posttest Total Scores and scores on the *Entropy and Second Law* sub-measure compared to their pretest scores, while students in both the inverted and traditional sections scored comparably on the CTP assessment (also Engineering 82). In Math 45, students performed comparably across assessments. Also important from evaluation question #3 is the issue of how the inverted model impacts underprepared students. Unfortunately, we were not able to perform this sub-group analysis given the small sample size of this population. However, we will continue to examine data in the coming years to determine if this analysis can be performed.

Student Transfer of Knowledge
Transfer of knowledge can be defined as the ability to apply material in new situations. Literature on knowledge transfer identifies several areas that may promote the transfer of knowledge (e.g., Pugh & Bergin, 2006), but how the inverted classroom model can impact the knowledge transfer has yet to be explored in the literature. Research suggests knowledge transfer occurs with changes in subject-matter knowledge, situational and individual interests, and general strategic processing (Alexander & Murphy, 1999). The inverted classroom model may create changes in student interests and metacognition and in turn may impact transfer of knowledge.

Research Question 3: Do students in inverted classrooms demonstrate an increased ability to apply material in new situations as compared to students in traditional classrooms?

Student Transfer of Knowledge Results
The next evaluation question addresses the issue of a specific metacognitive skill, transfer. Transfer of knowledge can be defined as the ability to apply material in new situations. Literature on knowledge transfer identifies several areas that may promote the transfer of knowledge (e.g., Pugh & Bergin[9]), but how the inverted classroom model can impact the knowledge transfer has yet to be explored in the literature. Research suggests knowledge transfer occurs with changes in subject-matter knowledge, situational and individual interests, and general strategic processing (Alexander & Murphy[10]). The inverted classroom model may create changes in student interests and metacognition and in turn may impact transfer of knowledge.

Engineering 82: Transfer Gains from Thermal Inquiry Projects
Students were given the assignment to investigate two "inquiries" of their choice over the course of the semester. The main purpose of these projects was to provide students with a project to get them "thinking about thermodynamics beyond the textbook" (TIP student handout). Each project was completed with a partner. Both pretest (based on a project rough draft) and posttest scores were provided for the first TIP only. For the second TIP, only posttest scores were provided.

For the first TIP, a total of 39 students received complete pretest and posttest scores. Since both pretest and posttest scores were provided for the first TIP, a Repeated Measures ANOVA was used to determine if there were statistically significant differences between students in the traditional section and the inverted section. *Results indicated that students in the inverted section performed better from pretest to posttest on the first TIP in the areas of: Communicate Effectively (Paper) and Identify and Formulate Problems*. Additionally, though not statistically significant, students in the inverted section also showed a greater rate of change from pretest to posttest on the overall weighted total TIP 1 score compared to students in the traditional section (see **Table 7**). These results suggest that the inverted section may have provided students with a slight advantage of transfer of knowledge over students in the traditional section on the first TIP.

Table 7. Thermal Inquiry Project 1: Repeated Measures ANOVA (*n* = 39)

Measure	Traditional		Inverted		*df*	*F*	*p* value
	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
TIP 1: Communicate Effectively (Paper)*	3.40 (.84)	3.86 (.74)	2.69 (.51)	3.75 (.75)	37	5.25	**.028**
TIP 1: Identify and Formulate Problems*	4.44 (.65)	4.82 (.53)	3.38 (.92)	4.68 (.77)	37	11.49	**.002**
TIP 1: Apply Knowledge and Solve Problems*	3.96 (1.03)	4.75 (.41)	3.63 (1.23)	4.63 (.76)	37	0.76	.391
TIP 1: Understand Impact*	2.76 (.52)	3.80 (.70)	2.25 (.68)	3.40 (.55)	37	.36	.553
TIP 1: Weighted Total**	39.28 (6.93)	49.91 (2.38)	33.19(8.32)	48.10(7.00)	37	2.71	.108

Note: * 5 points possible ** 50 points possible

Table 8. Thermal Inquiry Project 2: Comparison of Traditional and Inverted Scores (*n* = 48)

Measure	Traditional Mean (*SD*)	Inverted Mean (*SD*)	*t*	*df*	*p* value
TIP 1 (Post Only): Communicate Effectively (Poster)*	4.03 (.59)	3.80 (.50)	1.45	46	.154
TIP 2: Communicate Effectively (Paper)*	3.86 (.61)	3.63 (.67)	1.26	46	.216
TIP 2: Communicate Effectively (Poster)*	4.04 (.49)	4.05 (.51)	-0.10	46	.922
TIP 2: Identify and Formulate Problems*	4.89 (.28)	4.95 (.22)	-0.75	46	.458
TIP 2: Apply Knowledge and Solve Problems*	4.76 (.48)	4.77 (.50)	-0.03	46	.976
TIP 2: Understand Impact*	3.9 (.51)	3.90 (.85)	.054	46	.957
TIP 2: Weighted Total**	50.29 (3.02)	50.25 (3.74)	.037	46	.971
TIP 1 and TIP 2 Total Post Score***	100.20 (4.37)	98.35 (7.17)	1.02	46	.274

Note: * 5 points possible ** 55 points possible post ***105 points possible

For the second TIP (as well as the poster scores for the first TIP), since only posttest scores were available, an independent samples *t*-test was used to calculate if there were any differences in the performance of students in the inverted section versus the traditional section. A total of 48 students received posttest scores for the second TIP. *There were no significant differences between inverted and traditional section mean scores* (see **Table 9**), including the combined total post scores for both TIP 1 and TIP 2, indicating students in both sections performed comparably.

Math 45: Transfer Gains from Final Exam Results

There were three questions (i.e., Questions 4, 5, and 9) on the final exam of Math 45 that were designated as measures that could test students' ability to apply course material to novel situations (transfer). An independent samples *t*-test was used to calculate if there were any differences in the performance of students in the inverted section versus the traditional section. Each question was analyzed separately as well as combined into a single score. Results showed that students performed similarly on each of these measures, although students in the inverted section did exhibit higher scores (though not statistically significantly higher) on Question 5 compared to students in the traditional section (see **Table 9**).

Table 9. Students' Ability to Apply Course Material to Novel Situations: Math 45

Measure	Traditional Mean (*SD*)	Inverted Mean (*SD*)	*t*	*df*	*p* value
Question 4*	8.19 (2.32)	8.18 (2.66)	-.027	143	.978
Question 5*	6.70 (2.70)	7.49 (2.63)	1.78	143	.077
Question 9**	9.78 (2.23)	9.94 (3.39)	.296	143	.768
Composite of Questions 4, 5, and 9	8.22 (2.08)	8.54 (2.19)	.883	143	.379

Note. * 10 points possible **14 points possible

Student Transfer Gains Summary

Overall, students in the inverted section of the Engineering 82 course scored significantly better on some measures of knowledge transfer compared with students in the traditional section. No such knowledge transfer skills were observed in the Math 45 courses. Though students in the inverted section of Math 45 exhibited higher scores on Question 5 on the posttest, this was not statistically significant.

Student Metacognitive Gains Results

We had hypothesized that students in the inverted sections would show metacognitive gains stemming from their ability to review or re-watch the lecture videos; in addition, to being able to control the pace of the lectures as they were watching them. Having the ability to control the number of views and the pace of the videos is related to regulation of cognition (as opposed to knowledge of cognition), which is one of the two major components of metacognition reviewed by Schraw and Dennison (1994). Thus, students having the opportunity to review lectures and control their pace may lead to increases in metacognitive self-regulation.

Evaluation Question #5: Do students in inverted classrooms demonstrate increased metacognitive gains as compared to students in traditional classrooms?

The original MSLQ contains four main constructs[1] of which one is associated with Evaluation Question #6 (i.e., Metacognitive Self-Regulation). In addition, other questions were added to

[1] Constructs are theoretical concepts or ideas that are generally established through the combination of three or more survey items.

student surveys in 2013 generated from MAS. For this evaluation, the student survey was modified and used a subset of the original questions. With these modifications, we wanted to determine if these changes resulted in a stable construct that could be used to determine overall growth of metacognition in students. The analysis resulted in an overall Cronbach's Alpha equaling .79 which is only slightly below the desired level of .80 that is expected from an established scale.

We conducted the analyses to determine if there were any differences between inverted and traditional classrooms on student self-reported metacognitive self-regulation using a matched comparison. The analyses showed no significant differences from pretest to posttest, but students in the inverted sections of Math 45 decreased in their ratings of metacognition whereas students in the traditional sections of Math 45 increased from pretest to posttest, as was the case for all other groups (see **Table 10**). It is noteworthy that for Math 45, only a small portion of the total sample of Math 45 students (79 out of 149) were part of this analysis, which required complete pretest and posttest scores. Therefore, results should be interpreted with caution.

Table 10. Metacognitive Gains for Engineering 82, Math 45, and Combined

Group	**Traditional**		**Inverted**		***df***	***F***	***p* value**
	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
Engineering 82	3.72 (.56)	3.99 (.63)	3.59 (.74)	3.93 (.44)	1, 35	0.244	.624
Math 45	3.76 (.35)	3.84 (.45)	3.70 (.36)	3.66 (.49)	1, 77	1.663	.201
Combined	3.76 (.42)	3.89 (.52)	3.67 (.51)	3.74 (.49)	1, 116	0.422	.517

Scale: 1 = *Strongly Disagree* to 5 = *Strongly Agree*

Student Metacognitive Gains Summary

Student survey results indicate that there were no significant differences between the students in the traditional and inverted sections. For students in Math 45, ratings in the inverted section decreased from pretest to posttest (though this decrease was non-significant). It is plausible that although students in the inverted sections had the opportunity to review and regulate the pace of lecture, students did not take advantage of these benefits or this process alone did not facilitate change in their metacognitive self-regulation as hypothesized. Additionally, it is possible that the format of the inverted sections was not distinct enough from traditional sections to demonstrate measurable differences in metacognition. Adding specific examples or discussions of metacognitive self-regulation, specifically with students in inverted sections in future years, may lead to greater changes for these students during the courses.

Additional Gains

The student survey additionally measured students' growth over the course of the class in the areas of self-efficacy and peer learning. For students in the Engineering 82 course, no significant differences were observed between traditional and control students related to the rate of change in these areas from pretest to posttest. For participants in Math 45, students in the traditional section had larger gains in self-efficacy from pretest to posttest (though this difference was not statistically significant). Notably, students in both the traditional and inverted sections of Math 45, along with students in the inverted section of Engineering 82, showed lower peer learning scores on the posttest compared to the pretest. This is possibly due to students anticipating different peer learning behaviors at the beginning of class compared to their actual experience (see **Table 11**).

Table 11. Self-Efficacy and Peer Learning Gains for Students

Group	**Traditional**		**Inverted**		***df***	***F***	***p* value**
Engineering 82	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
Peer Learning	3.83 (.50)	3.85 (.58)	3.61 (.67)	3.51 (.58)	1, 35	.242	.626
Self-Efficacy	3.78 (.96)	3.96 (.86)	3.82 (1.01)	4.00 (.57)	1, 35	.001	.972
Math 45							
Peer Learning	3.74 (.51)	3.56 (.62)	3.68 (.53)	3.45 (.57)	1, 77	.207	.651
Self-Efficacy	3.40 (.66)	4.05 (.63)	3.45 (.70)	3.83 (.75)	1, 77	2.799	.098

Student survey results were analyzed further to see if any notable differences in individual survey items were found between: pretest scores of students in inverted and traditional sections for both courses; posttest scores of students in inverted and traditional sections for both courses; pretest scores of students in Engineering 82 versus pretest scores of students in Math 45; and posttest scores of students in Engineering 82 versus posttest scores of students in Math 45. Notable results are shown below in **Table 12.** Tables for each of these full analyses can be found in **Appendix B**.

Table 12. Significant Results for Full Student Survey Analyses

Time of Administration	**Individual Survey Items**	**Significant differences *M* (SD)**
	Traditional vs. Inverted	
Pretest	I expect to do well in this class.	Traditional *M* = 3.83 (0.81) **Inverted *M* = 3.94 (0.68)**
	I try to identify students in the class whom I can ask for help if necessary.	**Traditional *M* = 3.87 (0.86)** Inverted *M* = 3.63 (1.04)
Posttest	I am confident I learned the basic concepts of E82/MAT45	**Traditional *M* = 4.53 (0.53)** Inverted *M* = 4.34 (0.70)
	Engineering 82 vs. Math 45	
Pretest	When I become confused about something in a lecture, I go back and try to figure it out.	E82 *M* = 3.87 (0.98) **MAT45 *M* = 4.00 (0.55)**
	I have control over how well I learn.	E82 *M* = 3.56 (1.00) **MAT45 *M* = 3.78 (0.79)**
	When studying, I often try to explain the material to a classmate or friend.	**E82 *M* = 3.62 (1.16)** MAT45 *M* = 2.93 (1.03)
Posttest	I try to identify students in class whom I can ask for help if necessary.	**E82 *M* = 3.95 (0.93)** MAT45 *M* = 3.56 (1.17)

	I ask the instructor to clarify concepts I don't understand well.	**E82 *M* = 3.89 (0.76)** MAT45 *M* = 3.44 (0.94)

Gender Effects

Students' achievement and survey results for E82 students were examined for potential differences between males and females by comparing the rate of growth from pretest to posttest between males and females and by investigating differences in males' and females' responses on items that were not assessed using a pretest-posttest (e.g., specific questions only on the posttest student survey). Data for all three years of the Engineering 82 course administration (fall 2012, fall 2013, and fall 2014) were combined across conditions. Males and females performed similarly on most measures used in the Engineering 82 course, though several statistically significant differences were found (see **Table 13**).

Table 13. Summary of Differences Found

Measure	Difference Between Males/Females	Specific Difference
Student survey – peer learning	No	n/a
Student survey – self-efficacy	Yes	Females showed greater growth pre to post
Student survey – metacognition	No	n/a
Student survey – course elements	Yes	Females showed higher ratings for two elements
Thermal Inquiry Projects	Yes	Females showed higher TIP 2 and Total scores
Thermal Concept Inventory	No	n/a
Chemical and Thermal Processes Inventory	No	n/a

The first significant difference was found in responses on the student survey, which assessed students in the areas of peer learning, self-efficacy, and metacognition. Females showed significantly higher growth in the area of self-efficacy from pretest to posttest compared to males (see **Table 14**). Interestingly, the average male's score decreased from pretest to posttest while the average female's score increased from pretest to posttest. This could indicate that males overestimated their self-efficacy while females underestimated their self-efficacy prior to taking the course or increased their self-efficacy during the course.

Table 14. Student Survey Construct Scores

Construct	Males		Females		*df*	*F*	*p* value
	Pre Mean (*SD*)	Post Mean (*SD*)	Pre Mean (*SD*)	Post Mean (*SD*)			
Peer Learning*	3.67 (.61)	3.54 (.58)	3.85 (.41)	3.81 (.57)	1, 117	0.659	ns
Self-Efficacy**	3.93 (.66)	3.77 (.73)	3.42 (.71)	3.56 (.66)	1, 122	**6.09**	**.02**
Metacognition*	3.55 (.55)	3.60 (.55)	3.60 (.41)	3.69 (.45)	1, 117	0.122	ns

* - males, *n* = 69, females, *n* = 50
** - males, *n* = 71, females, *n* = 53
ns = not significant; bold = statistically significant difference

In fall 2014, new questions were added to the posttest student survey which asked students to rate the extent to which certain elements of the course contributed to their learning. For students in the flipped section, these elements included homework, daily quizzes, video lectures, and in-class activities. For the traditional section, these elements included homework, in-class lecture, and i>Clicker problems. There were no significant differences between males and females in the traditional section responses, but there were two significant differences for the flipped section students. Specifically, females indicated homework and in-class activities both contributed to their learning to a greater extent than did males (see **Table 15**). It should be noted that due to the small sample size, these results should be interpreted with caution.

Table 15. Course Element Ratings – Flipped Section

Course Element	Gender	*n*	Mean (SD)	*t*-test	*p*-value
Homework	male	19	4.26 (.65)	**2.06**	**<.05**
	female	12	4.75 (.62)		
Daily Quizzes	male	19	3.21 (.71)	.91	ns
	female	12	2.92 (1.08)		
Video Lectures	male	19	4.21 (.71)	.16	ns
	female	12	4.17 (.84)		
In-Class Activities	male	19	3.79(1.03)	**2.47**	**<.05**
	female	12	4.58 (.52)		

ns = not significant; bold = statistically significant difference

The Thermal Inquiry Project (TIP) scores also showed differences between males and females for both scores on the second TIP item as well as the total TIP score. Females scored higher than males for both of these (see **Table 16**).

Table 16. Thermal Inquiry Project Scores

Test and Administration Time	Gender	*n*	Mean (SD)	*t*-test	*p*-value
TIP 1	male	80	50.36 (2.55)	1.08	ns
	female	57	50.81 (2.13)		
TIP 2	male	80	49.86 (3.44)	**2.31**	**<.05**
	female	55	51.23 (2.60)		
Total TIP	male	80	100.22 (4.47)	**2.31**	**<.05**
	female	55	101.93 (3.79)		

ns = not significant; bold = statistically significant difference

Finally, there were no statistically significant differences between males and females related to growth from pretest to posttest on the Thermal Concept Inventory (TCI) and Chemical and Thermal Process (CTP) inventory scores.

Student Satisfaction with Inverted and Traditional Classrooms

The next section provides feedback from students regarding their experiences in the participating courses. Although student satisfaction with the inverted classroom was not specifically related to an evaluation question, we felt it was important to gauge students' experiences, given that most students did not have prior experience with the inverted classroom model.

The following contains a summary of open-ended comments for both courses. The comments from students in both Engineering 82 and Math 45 were anonymous feedback generated from the Harvey Mudd College course evaluations. Students responded to the following two questions: 1) *What aspects of the teaching or content of this course do you feel were* especially *good?* and 2) *What changes could be made to improve the teaching or content of this course?*

Engineering 82: Student Satisfaction Results

A majority of students in the inverted classroom reported more positive feedback than negative feedback about the course. Overall, students in the inverted section appreciated the practice in class and wanted the video lengths to be consistent. One student commented, "*I loved being able to do practice problems in class- asking questions while solving problems was useful*." In comparison, students in the traditional section appreciated the clear and organized lectures and would change the length of homework and assignments. **Table 17** summarizes the major findings for the Engineering 82 course.

> *"The flipped classroom format worked for me, I was able to learn on my own time and the reduced problem sets were a good balance between cutting the time taken to do homework and reinforcing concepts with practice. Please teach both sections like this in the future!"*

Table 17. Engineering 82: Key Benefits, Key Drawbacks and Major Differences by Students

Key Benefits	Key Drawbacks	Perceived Differences between Course Formats
• Practice time during class • Access to professor during class time while working through problems • Ability to pause and re-watch video lectures for review and study for exams	• Length of videos were inconsistent and made it hard to manage time • Inability to ask questions/ have class discussions in real time during lectures • Pacing of video lectures is not responsive to student needs	• Students in the traditional section reported that the inverted section students had less homework • Students in the inverted section reported having less homework but spent more time watching videos outside of class

Math 45: Student Satisfaction Results

Overall, most students believed that the instructor and course material were especially good aspects about the course. Students referred to the *instructors* as *helpful* and *accessible* and the *course material* as *interesting*. In addition, students in both sections indicated that the modeling problems were either an especially good course component or one of the areas that could benefit from changes to improve the course. For example, a student in the inverted section commented, "*I think the modeling problems tended to get a bit contrived. While it is a good idea to show that DE's are useful in real life, many of the scenarios are actually too complicated to accurately describe using the techniques in an intro class…*" Conversely, a student in the traditional format commented, "*I really liked the modeling aspect of the class. It was interesting to see how DE's could be used to model real-world situations*."

In comparison to the mixed opinions with modeling problems, students in both sections were united when discussing the *course grading*. Students believed that the grading, specifically on homework and quizzes, was hard and unfair. However, both the utility of modeling problems and grading policies appear to be an overall course design concern versus an issue with the flipped or traditional classroom setting. Specific discrepancies and commonalities between the flipped and traditional structures will be discussed in further detail below.

Perceived Learning Styles

Students in the inverted sections explicitly indicated that both of the formats were aligned with their specific learning style (see **Table 18**). Overall, students in the inverted sections either indicated that they enjoyed the course because they could go at their own pace or did not enjoy the course because they wanted live lectures with feedback in real-time. Although rarely stated, students in the traditional sections expressed opinions about the match of learning style and course type. One student commented, "*Having a class and not in the flipped section- I enjoyed being in lecture more than the videos (some of which I watched) and I feel the in-class homework time would not benefit me*." Another student indicated that it may be beneficial to have students pick which section to enroll in the future.

Table 18. Student Perceptions of Course Alignment with Learning Style – Inverted Student Responses

Satisfied
"I enjoyed being in the flipped section. I thought it was helpful to have class time to work on homework sets and I liked the capability to pause the video to take notes and try example problems."
"I love the flipped classroom idea, especially for a methods class like this one. I like to learn at my own pace."
"I like the idea of the flipped class. I like having the videos to go back and watch the lecture again."
Unsatisfied
"For me personally, the flipped classroom was not an effective learning method. I find videos to be much less effective than live lecture since they are extremely difficult for me to pay attention to."
"Also, I'm really not a fan of flipped classrooms- I feel like they oppose what this school stands for."
"Although the flipped class had its advantages, I often didn't get all that I wanted out of the videos and didn't feel that attention during class was well distributed."

Pacing

Students also commented about the pacing of the course. Students in the inverted sections enjoyed being able to learn the material at their own pace. Similar to comments above, one student commented, "*I loved the flipped videos because I learn so much more going at my own pace*." Conversely, some students in the traditional format felt rushed. One student commented, "*Go slower! The way this class is taught does not work for people who want to take notes*." In addition, students in the traditional format wanted additional time spent on practice in class, especially when the content was new. One student mentioned, "…*during lectures the new material was not focused on and given enough time in the lecture. This caused some of the concepts to be unclear*." Another student commented, "… *I wish there had been just a little bit more practice with the techniques*."

Learning Materials
Finally, students in both the traditional and inverted sections commented that they liked the materials associated with the course. Specifically, students in the traditional section frequently commented that they enjoyed the slides and lecture notes. One student commented, "*I thought the lecture notes being on Sakai was really helpful*." Another student commented, "*The slides were very useful and thorough. They were very good study guides*." Similarly, students in the flipped section appreciated the notes and videos. Conversely, a student in the flipped section indicated, "*The videos were great in helping my learning. It was easier to learn at my own rate*." When referring to the class notes, one student noted, "*The notes are also very helpful*!" Students in both sections appreciated having materials to go back and reference before quizzes or exams.

Student Satisfaction Summary
Similar to the previous year, students showed mixed opinions overall regarding the inverted classroom design. Direct comparisons between Engineering 82 and Math 45 were difficult considering the sources for student comments differed in both courses; however, students seemed to have strong opinions whether positive or negative regarding the inverted classroom.

Faculty Preparation and Satisfaction
The final evaluation question was related to faculty experiences in preparing for and teaching with the inverted classroom model. Given that pre-recording video lectures and designing in-class exercises can potentially be a significant workload for faculty, their experiences were important to include in an evaluation of the inverted model to weigh the costs and benefits of the design in relationship to relative gains.

Evaluation Question #7: What are faculty experiences when teaching inverted course sections?

Two of the participating faculty members provided responses to a course reflection survey on the contrasts between traditional and inverted models. In addition, the third faculty member previously provided responses for the Engineering 82 courses for the 2012-2013 academic year. There were mixed opinions among the faculty members regarding the utility of class time to clear up student misconceptions or answer questions in the inverted section versus the traditional section. For example, one professor indicated, "*In the inverted course, it was relatively easy to observe when students had misconceptions because we assigned problems that would bring up these misconceptions and I circulated around the class. I would have conversations with people if I noticed them exhibiting the misconception*." In contrast, the professor noted that misconceptions in the traditional course "*only arose by the way of students' questions*". However, another faculty member noted, "*I don't think students were using their time particularly well in the inverted section. Fifty minutes seems short to work on a problem and have time to discuss it as a group*." In addition to these comments, **Table 15** provides a list of faculty quotes on their perceptions concerning the strengths and challenges of the classroom models.

Faculty Preparation and Satisfaction Summary
Overall, in their reflections, the two faculty members expressed the strengths and challenges of both the inverted model in comparison to the traditional classroom model. As seen in **Table 19**, both models had varying strengths and challenges. Generally, the differences were between the

two formats were in addressing misconceptions, time constraints, and student understanding of the material. Outside of the intended differences of the inverted classroom model, faculty experiences were mixed with regard to interactions with students. One faculty member indicated that the inverted section was not as enjoyable to teach. In addition, one faculty member reflected on the students' lack of choice for the course format (a necessity for the current study design) "*Students complained more about lack of choice of section. I wondered how much attitudes about the course might have improved if the students had chosen the type of section. Then, even if they regretted their choice later, they might have learned something about their own learning*."

Table 19. Faculty Perceptions of Strengths and Challenges of Course Models

Strengths of the Inverted Classroom • "Ability to interact with students while they built understanding of course material and problem solving" • "Students have additional time with me as their instructor working on mathematical tasks, which is when misconceptions are more likely to arise" • "ESL students liked the videos" • "Richer discussions " • "Motivated students took advantage of the ability to re-watch videos" • "Videos seemed to answer most student questions"	*Challenges of the Inverted Classroom* • "Students complained about lack of choice of section" • "Felt rushed for time" • "Students who needed more time to grapple with material being swept along by students who understood the material more quickly" • "I think mixing it up would have been more enjoyable for everyone and seemed more pedagogically sound than imposing one method or the other"
Strength of the Traditional Classroom • "Ability for students to ask questions as the course material is being introduced" • "Richer discussions" • "Students have real-time ability to ask questions ads they encounter new course content"	*Challenges of the Traditional Classroom* • "… misconceptions only arose by way of students' questions" • "Not knowing how well they were really understanding the material until I saw the HW scores and test performance"

Discussion and Next Steps

Following the second year of implementation, the inverted classroom model at Harvey Mudd College continued to show equivalent results for student performance in comparison to the traditional classroom model. While these findings still do not support original hypotheses of using the inverted model, there are possible explanations for these results. It is possible that the small sample size (particularly in Engineering 82) and some missing data from Math 45 inhibited a complete test of differences between the two groups. We expect to be able to combine data in the upcoming year to increase our power to detect actual group differences. In addition to the sample size issues, two additional possibilities for null results exist that were also considered in the first year's evaluation report and remain valid. These explanations include the characteristics of students that attend Harvey Mudd College as well as the nature of the implementation of the inverted classroom model.

Student Population

Students at Harvey Mudd College are generally higher performing than the average undergraduate student[2]. Thus, detecting differences in student performance may be difficult given a population of students that generally has high academic achievement regardless of the classroom design. This unique student population would not necessarily be observed in other undergraduate STEM programs. Using Harvey Mudd College students to test the efficacy of the inverted classroom may also explain why some students showed strong opposition to the inverted classroom design. That is, these students have most likely performed well in the traditional classroom setting and may have perceived the inverted classroom as a potential threat to their performance, or at the very least outside of their comfort zone. Furthermore, Harvey Mudd College students work extensively in groups both in and out of the classroom for the majority of their courses, so the inverted format would not provide a new benefit in regards to group work as it might in a campus where group work is more limited.

Implementation of the Inverted Classroom

Similar to the program setup in year one, the course formats were similar between the inverted and traditional classes. In year two, implementation continued to include similar assignments, homework, and tests regardless of the class format. The main difference for students between the two classroom models was when they had access to the professors for questions, during the lecture (traditional) or while doing homework (inverted). The data from the first two years of implementation at Harvey Mudd College suggested that the rearrangement of classroom activities and homework may not have a measurable effect on student performance. In addition, some elements such as allowing traditional students in Math 45 access to recorded lectures and other course materials results in de facto contamination of the experimental conditions. To ameliorate these challenges, some of the literature suggests that an expansion of the curriculum, rather than a mere rearrangement, is necessary to properly implement an inverted course model (Bishop & Vergeler, 2013).

Conclusions and Next Steps

As shown by the data above, the second year of this study, like the first, has shown little differentiation between the control and inverted sections in student learning or metacognitive gains. For the third year of the study, the instructors will institute additional activities in support of the inverted class sections that are distinct from the traditional sections (e.g., more discussion of strategies and misconceptions, special activities developed to address misconceptions). This should allow for a strong test of the program theory and reduce the likelihood that alternative explanations would be responsible for null findings in the future. Finally, during the fourth and final year of the study, instructors will likely implement a "hybrid" version of the model, where individual class sessions may be offered in either ran inverted mode or a more traditional mode depending on the content, as the faculty feel that some content is simply better covered in traditional in-class lecture than in an out-of-class video.

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[2] Student performance information located at http://www.hmc.edu/about1/fast-facts.html : freshman students (Class of 2016) scores ranged from 740 – 800 on the SAT (500 is average score). Also, approximately 92% of freshmen class were ranked in top 10% of their high school class.

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