

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

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Introduction

The inverted or “flipped” classroom has begun to attract much attention among educators in an effort to combine the use of technology and traditional teaching techniques. One definition of the inverted classroom was provided by Lage, Platt, and Treglia¹: “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). Bishop and Verleger² provide an expanded view of the inverted classroom by defining it as “an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom.”

Demonstrating the “buzz” around the inverted classroom, Bishop and Verleger² also located “39 unique blog posts or online new articles” touting the inverted classroom and its benefits for students. However, while the inverted classroom is gaining in popularity for education at all levels, educators have only a few resources to review that provide quality research of the benefits of the inverted classroom. In fact, most academic literature on the inverted classroom model comes from various conference presentations (e.g., Baker³; Bishop & Verleger²; Carlisle⁴; Dollar & Steif⁵). Also, there is literature available from peer-reviewed journals (e.g., Foertsch, Moses, Strikwerda, & Litzkow⁶; Lage & Platte⁷; Lage, Platt, & Treglia¹); however, these articles generally provide data on student attitudes towards the inverted classroom or compare student achievement outcomes to previous groups of students using the traditional classroom model. Only one study was located that used a quasi-experimental design for a Computer Interaction course. This study showed positive outcomes for the inverted classroom model in terms of student performance; however, pretest assessments were not used to establish group equivalence (Day & Foley⁸).

In an effort to study the inverted classroom model and add to the body of research, Harvey Mudd College implemented the inverted classroom model in selected classes during the 2012-13 academic year. This model was implemented during the Fall 2012 (Engineering 82: Chemical and Thermal Processes) and Spring 2013 (Math 45: Differential Equations). Specifically, one professor of Engineering 82 implemented one section of the inverted classroom model (i.e., treatment) and one section of the traditional classroom model (i.e., control); three Math 45 professors implemented a total of six sections (three inverted and three traditional) where each professor taught one of each of the classroom models. The same method of implementation is scheduled to occur for the 2013-14 and 2014-15 academic years.

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 following describes guiding research questions for the study.

Research questions:

1. Do students in inverted classrooms spend additional time actively working with instructors on meaningful tasks in comparison to those students in control classrooms?
2. Do students in inverted classrooms show higher learning gains as compared to students in traditional classrooms?
3. Do students in inverted classrooms demonstrate an increased ability to apply material in new situations as compared to students in traditional classrooms?
4. Do students in inverted classrooms demonstrate increased interest in and positive attitudes towards STEM fields as compared to students in traditional classrooms?
5. Do students in inverted classrooms demonstrate increased metacognitive gains as compared to students in traditional classrooms?
6. How satisfied are students and faculty with the inverted classroom model?

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. The class was ended by reviewing the solution to the problem and completing minute papers with a prompt for remaining questions on the course material, amongst others.

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 not. 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

The following measures were used to assess a variety of outcomes, including student attitudes towards STEM, overall learning gains, metacognitive gains and transfer of training. 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), 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 and the remaining items were from the MSLQ (18 items). The posttest contained the same items but added an additional 27 (for a total of 54) 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 research questions regarding interest in and attitudes about STEM. In addition to the surveys, students completed content assessments 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 includes 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 (Research Question 2).
- 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 (Research Question 2). The CTPs were scored by the instructor after the course ended; no names or section numbers were visible on the exams and the exams were graded in random order.
- 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 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 (Research Question 3). TIPs were graded in random order by the instructor.

Math 45 Achievement Measures

- The Math 45 **pretest and posttest assessments** were created by faculty members in 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 study, 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 (Research Question 2). 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. A composite score was created to address this for Research Question 3.
- There were five quizzes that were administered throughout the course and a **quiz composite score** was created that was the average of all the quiz scores with the lowest score dropped. The composite score was used to assess learning gains from pretest to posttest (Research Question 2).
- The **homework composite score** was calculated in the same manner as the quiz composite score. There were six 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 homework composite score was used to assess learning gains from pretest to posttest (Research Question 2).

Participants

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. **Table 1** summarizes participants' demographic characteristics. Analyses showed that the groups were equivalent at pretest (see "*p* of Chi-Square Test" in **Table 1**). Other demographic information analyzed include: 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 or not. 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.

Table 1. Student Participants' Gender and Ethnicity

Demographic Information		Inverted	Control	<i>p</i> of Chi-Square Test
All Students				
Gender	Female	46.2%	49.6%	.605

	Male	53.8%	50.4%	
Ethnicity	Asian	23.1%	26.5%	.375
	Caucasian	47.9%	42.5%	
	Other	17.1%	11.5%	
	Unknown	6.0%	8.0%	
Other Ethnicity Category	International Student	6.0%	11.5%	NA
Engineering 82				
Gender	Female	32.3%	39.1%	.601
	Male	67.7%	60.9%	
Ethnicity	Asian	22.6%	39.1%	.263
	Caucasian	41.9%	30.4%	
	Other	25.8%	8.7%	
	Unknown	3.2%	4.3%	
Other Ethnicity Category	International Student	6.5%	17.4%	NA
Math 45				
Gender	Female	51.2%	52.2%	.888
	Male	48.8%	47.8%	
Ethnicity	Asian	23.3%	23.3%	.835
	Caucasian	50.0%	45.6%	
	Other	14.0%	12.2%	
	Unknown	7.0%	8.9%	
Other Ethnicity Category	International Student	5.8%	10.0%	NA

Results

The following provides results for the first year of the study, 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 a limited measure of implementation for both the inverted and traditional course sections. Students in the traditional classes noted that the workload seemed “balanced” and “well distributed”. Those in the traditional classes appreciated that “working on the problem first, figuring out and trying it out for myself before asking others for help, allowed me to learn how to take a different perspective on a problem.”

Some students in the Math 45 inverted sections reported that they enjoyed working collaboratively on the homework assignments, with the main advantage being that “the professor was readily available to answer questions or clarify parts of the videos.” and “The fact that class time was dedicated to homework motivated me to actually begin the homework. That motivation was really valuable.” However, many students in the inverted classroom found it too “noisy” and “distracting,” with one commenting, “Sometimes I just left because I couldn't get any work done.” Several felt that class time was “mostly wasted”. Many students in the inverted classroom found it too difficult to be productive in class and many found it difficult to get the attention they felt they needed from the professor.

Overall, there was a fair amount of negative feedback from students for the inverted classroom design. A few students found it difficult to find the “*motivation to show up to class.*” Several felt that they “*didn't gain anything from class time because I was significantly less focused and productive in class than if I were doing homework on my own.*” Some felt that there was too much time spent reviewing concepts from the online videos, “*which essentially defeated the purpose of the flipped class,*” so, “*we didn't get much time to work on the homework.*” On the other hand, another student thought that “*more class-time could be spent just reviewing the concepts from the lecture at the beginning of class.*”

After combining student survey responses from Math 45 and Engineering 82, survey items related to this evaluation question tended to favor the traditional classroom design (see **Table 2**). Results suggested that students in the inverted sections were less likely to report that class time was helpful for learning the course concepts and felt less engaged than the students in the traditional sections.

Table 2. Student Survey Results

Measure	Traditional Mean (SD)	Inverted Mean (SD)	t	df	p value
Learning gains from working in small groups or teams*	3.50 (1.64)	3.42 (1.51)	-.39	221	.70
In this course, I often felt a sense of collaboration among students in the course.**	3.64 (.85)	3.77 (.82)	1.13	221	.26
The time spent in class helped me learn the concepts.**	3.89 (.85)	3.03 (1.25)	-5.91	220	< .001
I felt engaged during class meeting time.**	3.57 (.92)	3.42 (.87)	-1.31	221	.19

Scale: 1 = *No gain/very small gain* to 5 = *Very large gain* **Scale 1 = *Strongly disagree* to 5 = *Strongly agree*

Student Learning Gains

Research Question 2: Do students in inverted classrooms show higher learning gains as compared to students in traditional classrooms?

Engineering 82: Learning Gains from Thermal Concept Inventory

Students in both sections of the course, inverted and traditional, performed similarly when measuring their growth from pretest to posttest on the TCI. This analysis was completed for the overall score and each of the sub-measures available with the TCI measure. Specifically, all students had significant gains from pretest to posttest on the TCI total score. Also, all students showed significant gains for the Ideal Gas Law and Conservation of Mass sub-measures. However, all students, regardless of the section, did not show significant gains for: Entropy and Second Law, Internal Energy vs. Enthalpy, and Steady State vs. Equilibrium (see **Table 3**).

Table 3. Thermal Concept Inventory Growth from Pretest to Posttest (n = 44)

Measure	Traditional	Inverted
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	<i>t</i>	<i>df</i>	<i>p</i> value	<i>t</i>	<i>df</i>	<i>p</i> value
TCI Total Score	-4.01	15	.001	-2.87	27	.008
Entropy and Second Law	-1.81	15	.091	1.15	27	.260
Internal Energy vs. Enthalpy	0.00	15	1.00	-2.00	27	.055
Steady State vs. Equilibrium	-1.39	15	.186	.027	27	.791
Ideal Gas Law	-2.33	15	.034	-4.36	27	< .001
Conservation of Mass	-3.76	15	.002	-2.81	27	.009

To determine if there were differences between students in the traditional section and the inverted section, the TCI was analyzed using a Repeated Measures Analysis of Variance (ANOVA) given that a pretest and posttest were administered to students in both sections of the course. Results indicated that there were no differences in the rate of change between pretest and posttest for either the total score or any of the sub-measures when comparing the traditional section and the inverted section. Thus, students performed comparably on the TCI regardless of which section they were placed.

Engineering 82: Learning Gains from Chemical and Thermal Process Assessment

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 4**).

Table 4. Chemical and Thermal Process Growth from Pretest to Posttest (n = 51)

Measure	Traditional			Inverted		
	<i>t</i>	<i>df</i>	<i>p</i> value	<i>t</i>	<i>df</i>	<i>p</i> value
Problem 1: Identify & formulate problem	16.71	19	< .001	31.08	30	< .001
Problem 2: Identify & formulate problem	13.76	19	< .001	33.78	30	< .001
Total: Identify & formulate problems	16.87	19	< .001	40.69	30	< .001
Problem 1: Apply knowledge & solve problem	16.88	19	< .001	28.79	30	< .001
Problem 2: Apply knowledge & solve problem	13.69	19	< .001	21.17	30	< .001
Total: Apply knowledge & solve problems	17.24	19	< .001	30.25	30	< .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.

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 $M = 13.25$, control $M = 12.50$; $t(170) = 0.65$, *ns*] and posttest [inverted $M = 40.57$, control $M = 41.26$; $t(173) = -0.64$, *ns*]. While not statistically significant, the data suggest an interaction effect between the inverted sections and traditional sections such that the traditional sections showed a greater rate of change between the pretest and posttest than the inverted sections, $F(1, 170) = 1.91$, $p = .169$. This effect is

depicted in **Figure 1** where it can be observed that the traditional sections' average pretest score was lower than the inverted sections' average score at pretest but was higher at posttest. These results indicate that the students in the traditional sections slightly outperformed the students in the inverted sections but only in terms of pretest to posttest growth. That is, the difference in scores between the inverted sections and traditional sections is insignificant at pretest and posttest; however, the rate of change between the pretest and posttest assessments may slightly favor the traditional course model.

Figure 1. Math 45 Pretest and Posttest Scores: Inverted vs. Traditional



Math 45: Learning Gains from Homework and Quiz Composite Results

The homework composite scores showed no significant differences between the traditional sections and inverted sections [inverted $M = 90.78$, control $M = 92.24$; $t(173) = -1.28$, ns]. Analysis of the data showed that one student in the inverted section completed only two of the six homework assignments which resulted in a composite score that was much lower than all other students' scores, regardless of condition. For this reason, this student's score was removed from the analysis. We felt it is also important to note that all students but one who scored 80% or lower on their homework ($n = 9$) were in the inverted sections of Math 45. This suggests that participation in the inverted section may impair performance on the homework assignments for a certain sub-group of students. However, many of these students performed well on the exams and quizzes. Since half of these students mentioned struggled with procrastination, motivation, and time-management on the open-ended comments of the student survey, this may suggest that the poor performance on the homework assignments was due to study habits more than aptitude. 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 $M = 88.28$, control $M = 86.38$; $t(173) = 1.53$, 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 sub-measure *Internal Energy vs. Enthalpy* (Engineering 82), only students in the inverted classroom had marginally significant gains from pretest to posttest, but this had no impact on the overall score for the measure and was not significantly different from students in the traditional section in terms of growth rate from pretest to posttest. In Math 45, a trend suggested that students in the traditional sections had an advantage in their performance from pretest to posttest on the Math 45 assessment; however, this trend had no impact on the overall grade of the final exam when that comparison was made. Lastly, the homework composite score showed a trend that favored the traditional model; however, these differences also had little impact on the overall success of students in either course. 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

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 & Bergin⁹), 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 & Murphy¹⁰). 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 during the semester. For each inquiry, students generated a 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), and hence emphasized students’ knowledge transfer skills. Each project was completed with a partner.

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. Results indicated that students in the inverted section performed better on the Thermal Inquiry Projects (TIP) in

the areas of: *Ability to Apply Knowledge and Solve Engineering Problems in Thermodynamics* (TIP #1), the total weighted score (TIP #1), *Ability to Communicate Effectively on Paper* (TIP #2, marginally significant), and after combining the scores for TIP #1 and TIP #2 together (see **Table 5**). 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 TIP.

Table 5. Thermal Inquiry Projects: Inverted vs. Traditional Courses

Measure	Traditional Mean (SD)	Inverted Mean (SD)	<i>t</i>	<i>df</i>	<i>p</i> value
TIP 1: Communicate Effectively (Paper)*	3.98 (.38)	4.13 (.50)	1.206	52	.233
TIP 1: Communicate Effectively (Poster)*	3.76 (.42)	3.89 (.65)	0.807	52	.423
TIP 1: Identify and Formulate Problems*	4.98 (.10)	4.90 (.37)	-.932	52	.356
TIP 1: Apply Knowledge and Solve Problems*	4.57 (.53)	4.89 (.29)	2.790	52	.007
TIP 1: Understand Impact*	3.35 (.59)	3.58 (.95)	1.035	52	.306
TIP 1 Weighted Total **	48.89 (3.03)	50.76 (2.75)	2.444	52	.018
TIP 2: Communicate Effectively (Paper)*	3.88 (.35)	4.07 (.34)	1.903	50	.063
TIP 2: Communicate Effectively (Poster)*	3.69 (.70)	3.92 (.43)	1.465	50	.149
TIP 2: Identify and Formulate Problems*	5.00 (.00)	5.00 (.00)	0.000	50	1.000
TIP 2: Apply Knowledge and Solve Problems*	4.66 (.53)	4.81 (.37)	1.128	50	.265
TIP 2: Understand Impact*	3.36 (.65)	3.55 (.69)	1.003	50	.321
TIP 2 Weighted Total**	49.25 (3.04)	50.56 (2.31)	1.763	50	.084
TIP 1 and TIP 2 Total Score	97.94 (4.41)	101.31 (3.63)	2.976	50	.004

* 5 points possible ** 55 points possible

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 (see **Table 6**).

Table 6. Students' Ability to Apply Course Material to Novel Situations: Math 45

Measure	Traditional Mean (SD)	Inverted Mean (SD)	<i>t</i>	<i>df</i>	<i>p</i> value
Question 4*	8.69 (1.78)	8.35 (1.95)	-1.186	173	.237
Question 5*	7.29 (2.55)	6.96 (2.76)	-.809	173	.420
Question 9**	9.72 (2.99)	9.82 (3.16)	0.218	173	.828
Composite of Questions 4, 5, and 9	8.57 (1.70)	8.38 (1.86)	-0.693	173	.489

* 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.

Student Interest in STEM Results

Research Question 4: Do students in inverted classrooms demonstrate increased interest in and positive attitudes towards STEM fields as compared to students in traditional classrooms?

We theorized that students will experience increased interest in and positive attitudes towards STEM primarily through positive experiences in the inverted classroom including interactions with peers and the instructor, engagement in classroom activities, and increased learning. The structure of the inverted classroom (e.g., students can control pace of video, students participate in interactive activities during class time) may provide students with greater autonomy in their learning and engagement in the learning process. These factors are related to students' interest in and positive attitudes towards STEM (Christidou¹¹) which ultimately affects student achievement (Wigfield & Cambria¹²).

The student survey contained three items that were associated with this evaluation question. Students rated how excited they felt about learning new concepts, attitudes about taking more courses in the field (i.e., math or engineering depending on the course), and how prepared student felt for the next level of study in the field. Results showed significant differences between the students in the traditional sections and the inverted sections. Student responses for all courses are reported separately for each course as well as combined into a single analysis for each of these survey items (see **Table 7**). These findings suggest that, on average, students in inverted sections felt less enthusiastic and less prepared; however, the effect was stronger in the Engineering 82 course. While the student survey used in Year 1 included survey items that were associated with this evaluation question, we suggest that the survey be modified to include additional items that reflect student attitudes toward STEM.

Table 7. Student Attitudes Toward STEM Survey Responses

	Group	Traditional Mean (SD)	Inverted Mean (SD)	t	df	p value
In this course, I often felt excited about learning new concepts.	Eng 82	3.68 (.58)	3.17 (.87)	-2.276	47	.027
	Math 45	3.60 (.81)	3.54 (.83)	-0.492	171	.624
	Combined	3.62 (.77)	3.44 (.85)	-1.586	220	.114
I look forward to taking more courses in this field.	Eng 82	3.37 (1.12)	2.57 (1.07)	-2.510	47	.016
	Math 45	3.64 (1.00)	3.66 (.83)	.132	172	.895
	Combined	3.59 (1.02)	3.37 (1.01)	-1.603	221	.110
I feel well prepared for the next level of study in this field.	Eng 82	4.00 (.82)	3.20 (1.06)	-2.795	47	.007
	Math 45	3.89 (.76)	3.82 (.73)	-0.568	172	.571
	Combined	3.91 (.77)	3.66 (.87)	-2.242	221	.026

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

Student Interest in STEM Summary

Overall, students in the traditional courses reported more positive attitudes towards STEM and STEM courses in comparison to students in the inverted sections.

Student Metacognitive Gains

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

Students in the inverted sections were expected to 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 Dennison¹³. Thus, students having the opportunity to review lectures and control their pace may lead to increases in metacognitive self-regulation.

The original MSLQ contains four main constructs (theoretical concepts or ideas that are generally established through the combination of three or more survey item), one of which is associated with Evaluation Question #6 (i.e., Metacognitive Self-Regulation). The MSLQ has 12 survey items that make up this construct. For this evaluation, the student survey was modified and used only eight of the items of the MSLQ because the other four items were not applicable to these courses. 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 .62 which is well below the desired level of .80 that is expected from an established scale, thus indicating that this survey may not be fully measuring the construct that is intended.

Although there were limitations in using the current survey measure, we still conducted the analyses to determine if there were any differences between inverted and traditional classrooms. The analyses did not show any significant difference from pretest to posttest (see **Table 8**).

Table 8. 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	3.37 (.39)	3.41 (.43)	3.44 (.34)	3.55 (.48)	1, 47	0.184	.670
Math 45	3.31 (0.46)	3.34 (.54)	3.29 (.47)	3.34 (.48)	1, 169	0.084	.772
Combined	3.32 (.45)	3.35 (.52)	3.33 (.44)	3.39 (.49)	1, 218	0.280	.597

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

Student Metacognitive Gains Summary

Currently it is unknown if these findings are a result of the Metacognitive Self-Regulation construct being incomplete or if, in fact, there were no differences between the students in the traditional and inverted sections. 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.

Satisfaction with the Inverted Classroom Model

Research Question 6: How satisfied are students and faculty with the inverted classroom model?

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 Engineering 82 and Math 45. The Engineering 82 comments were anonymous feedback from students generated from the student evaluations of teaching. 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?* Math 45 comments were responses to open-ended survey items that were only provided on the Math 45 posttest survey. Students responded to the following two prompts: 1) *Please explain what you found most valuable about the course structure* and 2) *Please discuss what you found the most difficult about the course structure.*

Engineering 82: Student Satisfaction Results

Only a slight majority of students in the inverted classroom had more positive feedback to report about the course in comparison to negative remarks. Students were polarized in their reactions to the inverted design with several students describing the format as “*great*” as they appreciated having the professor available to explain issues as they worked through problems. Others did not like the format at all, finding the video lectures “*difficult to follow*” and were frustrated at the inability to ask questions in real time as one would during a live lecture. One student noted, “*If there were a way to opt out of the pilot, I would have.*” Several students were irritated at not being able to leave the classroom when their work was complete, feeling that the format “*made the coursework take way longer than it should have.*” **Table 9** summarizes the major findings for the Engineering 82 course.

Table 9. Engineering 82: Key Benefits, Key Drawbacks and Major Differences by Students

Key Benefits	Key Drawbacks	Perceived Differences between Course Formats
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<ul style="list-style-type: none"> • Access to professor during class time while working through problems • Ability to pause and re-watch video lectures for review and study for exams 	<ul style="list-style-type: none"> • Inability to ask questions/ have class discussions in real time during lectures • Pacing of video lectures is not responsive to student needs • Some students “<i>didn’t feel connected to material</i>” 	<ul style="list-style-type: none"> • Watching videos was perceived as “<i>less stressful</i>” in terms of homework /coursework load by students in the inverted classroom • Students in the traditional section reported that the inverted section students were unfairly benefitting from more examples and explanations in class as well as a lighter work load
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Math 45: Student Satisfaction Results

Students were asked about the valuable and challenging aspects of the course *structure* on the student survey, though many focused their responses on course *content* instead. Regardless of condition, students most appreciated the *real-life applications* and connections to other science subjects offered in this course. The *online lecture notes* were found to be essential, with one student claiming “*they were how I learned the material, so they were the most valuable to me.*” Most students responded positively to the *homework assignments* being due once a week, though many complained that the homework was “*tedious*” and involved too much “*emphasis on computational skill, as opposed to mathematical skill.*” As one student noted, “*I was just doing heinous calculations, derivatives, and algebra for an hour on a problem, and only 10 minutes engaging with the new concepts.*”

Lecture Format, Pacing, and Student Focus

Students in the traditional sections commented that the *brain breaks* offered during in-class lectures helped students stay focused. One student felt that “*the pacing was just right.*” A few students did have some difficulty keeping up with *note-taking* during in-class lectures, but because students in the traditional section were granted *access to the online videos* and *lecture notes*, most found these to be effective supplemental resources. As one student commented, “*I liked having the option to watch the videos while also having lectures.*” Another noted, “*Complete lecture notes allowed me to review material by myself, which really helped me study and understand topics.*”

On the other hand, students in the inverted sections experienced only the video lectures as opposed to having an in-class lecture with online videos available. One student noted, “*I wish we also had the professors having lectures in class along with putting up the videos online.*” Another commented that the videos are valuable as “*an additional resource, but should not be the main source of information.*” Almost all students reported an appreciation for the ability to pause, rewind, and fast-forward through the video lectures: “*The videos were awesome. Incredibly helpful when I was confused about an idea; I could re-watch that snippet again and again.*” Others could not seem to learn from the video lectures, unable to overcome their frustration and confusion even with repeated viewing. There were some complaints about the

spacing of the video lectures and some found it difficult to maintain their focus while watching on their own. As one student noted, *“Personally, learning from listening to a professor lecture is more helpful to me than online videos.”* Another student commented that the poor quality of the recording was distracting. The inverted section students reported having difficulty scheduling uninterrupted time to watch the videos before class.

Asking Questions in Real Time

One of the more common grievances among the inverted section students involved not being able to ask questions in real time during the lecture and not being able to follow up adequately during class time. This was either because they could not keep track of what they found confusing in video lectures enough to articulate questions for class, or because they found it too difficult to get the professor’s attention when they needed help. However, some students in the regular classroom also found it *“difficult to form questions during class as I didn’t have many problems to apply it to.”*

The Inverted Design Overall

Some of the most positive responses to the inverted format involved students’ ability to learn at their own pace, for example:

“The videos really helped my learning, most likely because of the opportunity to try the practice problems at my own pace. In class, if we had practice problems, I would not even have a chance to try the problems and the class would have moved on, but the videos let me pause and take as much time as needed.”

“I really liked being in the flipped section. It enabled me to learn the new material at my own pace and take notes. In class, I could ask questions to clarify and then start the homework, again asking the professor for help.”

Several students were explicit in their preference for the traditional classroom structure due to the ability to ask questions in real time and for the greater sense of focus on and engagement with the lecture and the professor. One student suggested that Math 45 was not an appropriate course for an inverted design: *“I feel that this format could be interesting for harder, less straightforward classes, such as a course in number theory, but DEFINITELY not for a straightforward class like an introduction to differential equations class.”*

Student Satisfaction Summary

Overall, students showed mixed opinions 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 Satisfaction

What are faculty experiences teaching inverted course sections?

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 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.

Three of the participating faculty members provided responses to a course reflection survey on the contrasts between traditional and inverted models. There were mixed opinions that misconceptions could be identified and clarified more easily in the inverted classroom. Two of the professors indicated that in both formats, students did not leave class with many misconceptions, but the other professor thought the inverted classroom model was easier to uncover misconception, *“but not as easy as I was expecting – students spoke with each other more than with me, and may have even reinforced each other’s misconceptions in some cases.”*

Table 10 provides a list of faculty quotes on their perceptions concerning the strengths and challenges of the classroom models.

Faculty Preparation and Satisfaction Summary

Outside of the intended differences of the inverted classroom model, faculty experiences and interactions with students were similar. The faculty seemed to enjoy the inverted model and their interactions with students; however, they did experience some challenges including balancing work time with class discussions and feeling frustrated with only working on homework with students during this time.

Table 10. Faculty Perceptions of Strengths and Challenges of Course Models

<p><i>Strengths of the Inverted Classroom</i></p> <ul style="list-style-type: none"> • “Lively and interactive” • “Enjoyed the inverted classroom environment more” • “Individual responsibility on student” • “Ability to interact with students while they built understanding of course material via problem solving” • “Motivated students took advantage of the ability to re-watch videos” 	<p><i>Challenges of the Inverted Classroom</i></p> <ul style="list-style-type: none"> • “Don’t think that students got as much out of the flipped classroom experience because they were mainly working on homework” • “Balancing discussion time with work time” • “Students who needed more time to grapple with material being swept along by students who understood the material more quickly”
<p><i>Strength of the Traditional Classroom</i></p> <ul style="list-style-type: none"> • “Fun all-class dynamic” • “Lively and interactive” • “Ability for students to ask questions as the course material is being introduced” 	<p><i>Challenges of the Traditional Classroom</i></p> <ul style="list-style-type: none"> • “Not knowing how well they were really understanding the material until I saw HW scores and test performance” • “Addressing individual needs of all students”

Discussion

Following the first year of implementation, the inverted classroom model at Harvey Mudd College showed equivalent results in comparison to the traditional classroom model in terms of student performance. While these findings do not support original expectations of the inverted model, there are possible explanations for these results. One reason for the null results may be because of student population at Harvey Mudd College. Another reason may have been how the inverted classroom model was implemented. We will address each of these possibilities below.

Student Population

Students at Harvey Mudd College are generally higher performing than the average undergraduate student. 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 as there is a truncated student sample; 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: 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 as previously successful academically.

Implementation of the Inverted Classroom

Ultimately, this was a study of the effects of changing the order of activities for the students in Engineering 82 and Math 45. In Year 1 of implementation, students completed the same assignments, homework, and tests regardless of the classroom model in which they were situated. 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). Given this setup, an important question is was the intervention (i.e., the inverted classroom) powerful enough to cause a measurable and real difference in student performance? The data that were analyzed from the first year of implementation at Harvey Mudd College would suggest that merely the rearrangement of classroom activities and homework may not have a measurable effect on student performance. Some of the literature suggests that the benefits of inverting the classroom come from the ability for instructors to include additional classroom activities that were not feasible in the traditional classroom. Bishop & Vergeler² make this point in their review of the inverted classroom literature:

[A rigid definition of the inverted classroom] would imply that the inverted classroom merely represents a re-ordering of classroom and at-home activities. In practice, however, this is not the case.

Most research on the inverted classroom employs group-based interactive learning activities inside the classroom, citing student-centered learning theories based on the works of Piaget 1967 and Vygotsky. The exact nature of these activities varies widely between studies. Similarly, there is wide variation in what is being assigned as "homework". The inverted classroom label is most 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 inverted classroom actually represents an expansion of the curriculum, rather than a mere re-arrangement of activities. (p. 5)

Therefore, it is possible that these implementations are not representative of what would be possible in a true inverted classroom setup. Additionally, in the case of Math 45, traditional section students also had access to all inverted section materials, and it appears that the two groups were not distinct enough to have measurable differences in the two settings.

Next Steps

The evaluation of the inverted classroom design will continue at Harvey Mudd College for the 2013-14 academic year. Engineering 82 was offered again in the Fall 2013 semester and Math 45 will be offered to students in the Spring 2014 semester.

Changes to Inverted Classroom Model

In response to the 2012-13 results, student feedback, and faculty experiences, the instructors plan to make several modifications to the inverted class implementation in 2013-14. In the Fall 2013 offering of Engineering 82, the videos were modified to include reflection questions and to

require students to ask questions on the material. The in-class activities were modified to include rotating randomly assigned groups and more faculty-student interaction during class time, and each class session began by going over student questions from the videos. Similar changes are planned for the Spring 2014 implementation of Math 45.

Changes to Study Evaluation

A modified pretest survey was created with additional survey items in an effort to bolster the metacognitive construct. Additionally, some survey items were removed that were determined unnecessary for the evaluation. Analysis of the pretest survey administered to the Engineering 82 students will inform any modifications of the posttest survey.

Conclusions

With this work, we aim to investigate whether flipped classrooms benefit students because they create more time for proven techniques such as active learning, group work, project-based learning, or if there are other benefits that occur as a sole result of the way the instruction is delivered. We have developed a study design including control and treatment sections, pre-/post-content testing, and pre-/post-surveys aimed at evaluating metacognitive and affective gains. The preliminary results of these measures do not show improved student learning as a result of the inverted format as compared to an active-learning-based course format. However, these results are based on a relatively small number of students ($n = 196$ in the mathematics course and $n = 59$ in the engineering course). Furthermore, the instructors have made changes to the inverted course format to address perceived weaknesses in the pilot year implementation. As the study progresses, we hope to provide more conclusive answers to the study's research questions.

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