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Flipping Engineering Courses: A School Wide Initiative

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ABSTRACT

In the 2013–2014 school year, we implemented the "flipped classroom" as part of an initiative to drive active learning, student engagement and enhanced learning in our school. The flipped courses consisted of freshman through senior engineering classes in introductory programming, statics/mechanics, mechanical design, bio-thermodynamics, facilities layout/material handling, and chemical engineering dynamics and modeling. In the flipped classroom, students watch video lectures beforehand to obtain the foundational knowledge and then demonstrate skills during class. Our study set out to address the following research questions: 1) Does the flipped classroom promote student engagement during class, and does it positively impact the classroom environment?, 2) Is the flipped classroom associated with increased student achievement and learning of content?, and 3) What strengths, benefits, and drawbacks do students perceive with the flipped classroom? To address these, we used a mixed methods approach, including environment and evaluation surveys, instructor interviews, exam and homework results, video access data, and structured classroom observation. Based on our use of the College and University Classroom Environment Inventory (CUCEI), we found evidence that flipped instruction can positively impact the classroom environment. We also used a behavioral observation protocol – the Teaching Dimensions Observation Protocol (TDOP) – to assess student engagement and involvement during class. We compared our results to a national TDOP study of 58 lecture-based STEM classrooms, formally demonstrating the advantages of our flipped classrooms. Behaviors such as student discussion and questions and problem solving were significantly higher in our flipped classrooms ($p<0.0001$). Our pre-flip versus flip exam and homework results were mixed from a statistical improvement standpoint. However, based on instructor interviews we noted enhanced higher-order skills such as problem solving and deeper engagement and proficiency in some courses and with some students. Unfortunately, we encountered challenges with our freshman and seniors. The great majority of freshmen did not use the videos for first-time instruction. The seniors expressed resistance to and dissatisfaction with this instructional change. Both freshmen and seniors rated their classroom environments statistically lower than the sophomores and juniors did. We uncovered other instances in the literature of these challenges. Nonetheless, we believe that flipped instruction is a valuable approach for promoting engagement and learning. We discuss lessons learned, including the need to educate students about the expectations of the flipped classroom.

Key words: Flipped classroom, inverted classroom, assessment, behavioral observation, engagement, engineering education

INTRODUCTION

Complex topics, which are often encountered in university STEM courses, benefit from active learning exercises in which students can more fully construct an understanding of the topic [1]. However, traditional lecturing still occurs in large part in undergraduate STEM courses, and it is emerging as an ineffective way to educate students and help them fully understand the material [2–4]. To this end, the flipped classroom is an approach that enables students to practice and demonstrate their skills during class in the presence of the instructor or teaching assistant (TA) without loss of content coverage. With the flip, students' first exposure to the content is typically via online videos, while problem solving and skills application is undertaken during class with mentors present [5–7]. Such an active learning approach requires students to be engaged and involved in their learning and reduces the amount of passive class attendance [8–9]. Top educators have emphasized that meaningful learning occurs when students discuss, analyze, solve, apply, and otherwise get involved in their coursework [10]. Studies have shown that active or interactive learners exhibit significantly higher outcomes and gains compared to passive learners in regards to problem solving, time to mastery, and conceptual understanding [9, 11]. A recent meta-analysis of studies that compared active learning to the traditional lecture showed that exam performance increased by half a standard deviation (on average) in STEM courses that contained active learning. In addition, the average failure rate was 34% with traditional lecturing – but only 22% with active learning [4]. Flipped courses also lead to benefits such as increased student-teacher interaction, student teaming, individualized support, self-paced learning with "pause and rewind" capability, increased problem solving and concept application, and flexibility for those who cannot attend class for legitimate reasons such as varsity sports travel or job interviewing [12–13].

Given these advantages, Pitt's Swanson School of Engineering began to formally promote the flipped classroom across its various programs in the fall of 2013 with the assistance of its Engineering Education Research Center (EERC). A school-wide approach has the benefit of promoting this pedagogy from the beginning and then throughout the students' undergraduate careers. The school's objectives with the flipped classroom were the following: 1) enhance in-depth learning and achievement of higher-order skills in Bloom's taxonomy, 2) enhance student engagement in learning, and 3) better utilize the school's state-of-the-art instructional facilities and technology to support active learning. Interestingly, in a similar manner, approximately 1,100 faculty members from the US and Canada indicated that their top motivations for flipping the classroom included increasing student engagement (79%) and improving student learning (76%) [14]. In another recent survey by the National Center for Case Study Teaching in Science, instructors indicated they flip material to increase interaction with students, offer flexibility, and involve and engage students in their education [15].

The courses that we flipped are described in Table 1. Over 1800 students took these courses in the four semesters between fall 2013 and fall 2014 inclusive.

Across these various courses, the motivations and goals of the instructors for flipped instruction aligned well with the overall school-level objectives, as shown in Table 2.

Research Questions and Contributions

Our overall school-level objectives provided the basis and direction for our research questions. Our three research questions were as follows:

1. Does the flipped classroom promote student engagement during class, and does it positively impact the classroom environment?
2. Is the flipped classroom associated with increased student achievement and learning of content?
3. What strengths, benefits, and drawbacks do students perceive with the flipped classroom?

To address these research questions, we developed a customized, comprehensive assessment plan consisting of direct and indirect measures that aligned directly with the objectives of the initiative.

Course	Approx. Students Per Year	Level	Topics
Introductory Engineering Programming	700	Freshman/Transfer	Programming in MATLAB and C for engineering problem solving.
Statics/Mechanics	160	Sophomore	Statics and strength of materials; analysis of internal stresses, strains, and displacements.
Intro to Mechanical Engineering Design	200	Sophomore	Fundamentals of mechanical design; concept generation, graphical communication, CAD with SolidWorks, and material selection.
Bio-thermodynamics	90	Sophomore	Mass balance, conservation of energy, entropy, thermodynamic relations, applications to physiologic systems.
Facility Layout/ Material Handling	70	Junior	Space requirements, layout types and algorithms, facility location problems, warehousing, and material handling methods.
ChE Dynamics, Modeling & Control	100	Senior	Chemical engineering process and systems modeling, dynamics, and control.

Table 1. Courses Flipped.

These measures included course-embedded assessments such as exams and assignments, interviews and discussions with instructors, student perception surveys, structured classroom observation, and analysis of video usage data. The perception surveys included a classroom learning environment and a flipped classroom evaluation survey. For the evaluation survey, we developed a grounded-theory-based, qualitative framework that can be used by other education researchers to code open-ended

Course	Instructor Goals
Introductory Engineering Programming	Enhance programming skills through increased hands-on application and support during class.
Statics/Mechanics	Enhance mastery of fundamental skills. Engage students beyond rote learning. Promote a physical intuition for the problem. Enable more in-depth teaming during class.
Intro to Mechanical Engineering Design	Introduce more design activities during class. Increase teaming and group discussion during class. Increase oversight of the student design process.
Bio-thermodynamics	Enhance understanding and retention of material via increased practice and application in the classroom.
Facility Layout/ Material Handling	Use class for difficult topics; enhance understanding. Use class to engage students in problem solving and provide support.
ChE Dynamics, Modeling & Control	Promote “deep thinking.” Enhance analysis, problem solving, synthesis, modeling, and computation/ simulation.

Table 2. Instructors’ Goals with Flipping.

student responses about the perceived benefits and drawbacks of the flipped classroom. Based on a review of the literature, we believe our assessment plan and its implementation makes a novel and significant contribution to the literature that others can use to assess their flipped classrooms.

We believe our article is fairly unique in describing a school-wide implementation of flipped classes from multiple engineering disciplines from the first through senior years. Taking a school-wide approach has the advantage of introducing the method early to students, involving faculty from the freshmen through senior levels in the instructional changes experienced by students, and being able to gather multiple faculty perspectives simultaneously that can be used to better integrate the undergraduate curriculum. The school-wide initiative also enabled the collection of a large, freshman-through-senior sample of assessment data under a common evaluation plan. This dataset could be used to compare results for different academic levels and provide aggregate results based on large samples. Our review of the literature uncovered similar experiences with freshmen and seniors at other schools; therefore, our work adds to the depth of the flipped classroom results for these special student subsets.

LITERATURE REVIEW

Flipped Classrooms and Implementations at Other Institutions

The flipped classroom represents a shift from an instructor-centered learning environment to an environment focused on the student [16]. Traditional lecture tends to be instructor-centered, with students often missing points made by the instructor due to the pacing or being unable to transcribe the words of the instructor fast enough [17-18]. The flipped classroom, however, places “lecture” under the control of the student via pre-recorded videos or readings that are accessed before class; and during class, there is time for students to reflect on problems and apply the concepts being taught [17].

The flipped classroom represents not only an inversion of typical classroom and homework activities but also an inversion of expectations on students, including a shift away from passive participation [19]. The flipped classroom places more responsibility and expectations of active involvement on the student and, based upon the literature, has had mixed acceptance among students, possibly due to these new expectations [19]. The flipped classroom also entails a change in the faculty member’s role in the classroom from that of a content provider to a supporter of students’ analysis and mastery of material [17, 19]. This involves instructing at the higher levels of Bloom’s taxonomy, uncovering students’ misunderstandings, correcting the misconceptions, and answering students’ questions on the spot [16, 19]. The flipped classroom often involves more preparation time for faculty upfront, and given the large change that occurs for both instructors and students, some have proposed flipping only a portion of the class sessions within a course [17, 20].

In reviewing the literature for STEM courses that have been flipped by others, we determined that the flipped classroom has been implemented in similar engineering courses at other universities. These include mechanical engineering courses in statics, numerical methods, introductory mechanical design, and electronics instrumentation [21–25]. Two universities have used online statics materials for both flipped and blended classrooms [21–22]. These web-based statics materials were developed as part of the Open Learning Initiative (OLI) at Carnegie Mellon [26]. There have also been flipped implementations in an industrial engineering course in work design [27] as well as a biomedical engineering course focused on conservation of energy [28]. The flipped classroom has also been used in both senior-level and first year engineering courses. We found senior-level implementations in a mechanical engineering control systems course, an electrical engineering signal-processing course, and a software engineering course [29–32]. Although we did not uncover chemical engineering implementations in the literature, we did find a large collection of over 1,000 chemical engineering videos that have been successfully used by students to learn chemical engineering concepts [33–34]. We did uncover successful flipped classroom implementations in lower-level chemistry labs and organic chemistry, which are required courses for our chemical engineers [35–36]. First-year engineering offerings that have been flipped elsewhere include courses in computer applications and problem solving using Excel, MATLAB, and C [37–40], introductory engineering [41], and introductory engineering design [42].

In examining the direct assessment outcomes at other schools, the flipped versus non-flipped results have been mixed. At the University of Puerto Rico, an inverted classroom was implemented for several sections of a statics course. On the Concept Assessment Tool in Statics (CATS), students in the inverted sections scored statistically higher than students in the traditional sections (p=0.0076) [25]. At the University of North Dakota, several undergraduate mechanical engineering courses were flipped, including introductory design, introductory mechanics, and numerical methods [23]. In numerical methods, the traditional section had the highest achievement, with 82% earning a C or better. This compared to 72% in the flipped section. Over an extended period at Penn State in an environmental engineering course, there was no statistical difference in final exam scores across six semesters in which the course had been taught both traditionally and in flipped mode [43]. Interestingly, in the recent faculty survey discussed in the introduction, only one-half (55%) noted evidence of improved student learning [14].

Mixed reports can also be found relative to freshmen. At Ohio State, a significant change was *not* found in freshmen final exam grades [39]. At the University of Cincinnati, there was a significant improvement on only three of seven problems on the final exam, and there was no change on three problems and a significant drop on one [37]. In a comparison of achievement in senior courses, students in a flipped control systems course performed statistically better or equivalent to their traditional-course counterparts [29-30]. In a signal processing course, there was a clear improvement in student performance with the flipped classroom, with an overwhelming majority performing at a high level on the final exam, as never seen before [31].

Results from the literature indicate that some students prefer the flipped classroom while others do not. Fifty-four percent of the North Dakota on-campus mechanical engineering students preferred the flipped format [23]. Likewise, in an electronics instrumentation course taken by mechanical engineers, 56% indicated a preference for online videos versus traditional lectures [24]. There was some dissatisfaction at North Dakota that the instructor had not given "live" lectures in the campus-based courses [23]. Some instructors have considered the desirability and need for upfront mini-lectures in the flipped classroom [30, 44]. There are mixed reports in the literature of freshman preferences for the flipped classroom. In a computing course, survey respondents expressed a lack of preference for the fully-flipped classroom, with only 13% preferring it. The large majority (i.e., 72%) expressed a preference for a partially inverted classroom [38]. Yet, freshmen in another flipped engineering course in design rated the course as significantly more effective overall than did freshmen in the traditional course [42]. With flipped first-year engineering courses, a low level of classroom preparation is a theme that has been discussed in the literature [41, 45]. With seniors or upper-division courses, initial student resistance and frustration with inverted instruction has been discussed in the literature [29-31]. These outcomes and themes from the literature also surfaced in our own overall experiences with freshmen through seniors in the flipped classroom.

METHODS

Faculty and Course Development

Preparations for the flipped classroom began approximately six months before the start of the semester. In the spring of 2013 the EERC formed a learning community to guide school-wide preparations [46]. The community was comprised of various engineering faculty who were flipping courses, the assessment analyst, and the IT staff involved in the video creation and editing. Learning community meetings were held approximately every two months, in which various topics were discussed, including challenges regarding students and video development, assessment activities, classroom logistics, active learning techniques, and the instructors' goals and motivations. One of the challenges often discussed was students' use of the videos. We eventually came to the conclusion that we needed to better prepare students for our expectations of their responsibilities with the flipped classroom. This culminated with the creation of a "how to" video for students on being successful in the flipped classroom, which can be shared with students on day one. This video can be accessed at the following link: "How To" Flipping Video.

To further prepare the faculty, the EERC organized a one-day seminar in the spring of 2013, led by engineering faculty from another institution having experience with the flipped classroom. Also, one of the learning community members piloted three "flipped" lectures during the spring 2013 semester, prior to full implementation the following year. The information he was able to gather on the video recording, day-to-day assessment needs, and course and classroom logistics was very helpful to both him and others in the community.

Each instructor began creating his video lectures in the semester prior to the implementation semester. The instructors were provided with small school grants to support the development of their flipped courses. The lectures were recorded in small modules using the Camtasia software with the assistance of the IT staff [47]. Across the six courses, the videos ranged in average length from seven to eleven minutes. We aimed to keep the videos short (i.e., under 15 minutes) and modular, as recommended [7, 12]. As discussed in the literature, ten minutes may be an upper limit on students' attention spans [48]. To give an example of the modularity of the lectures, Table 3 contains sample video titles from the freshman programming course.

Assessment

Teaching Dimensions Observation Protocol (TDOP)

To assess engagement, involvement, active learning, and classroom dynamics and usage, we observed two class sessions in each flipped semester between fall 2013 and fall 2014 using the Teaching Dimensions Observation Protocol (TDOP) [49]. We were able to collect pre-flip observation data for two courses in the spring of 2013. We observed class sessions at approximately the one-third and two-thirds points in the term. In using the TDOP, the total class period was divided into a series of consecutive five-minute observation segments, or windows. Thus, in a given class period, multiple five-minute time segments existed and were observed. For example, a 50-minute class would have had 10 observation segments. In each segment, various activities and practices

Branching – "If" Basics	Looping – For Loops
Branching – "If" Example	Looping – Avoiding Infinite Loops
Looping – While Loops	Application – Random Numbers

Table 3. Modularity of Videos (Freshman Programming Course).

within the protocol were recorded when observed. The dimensions that describe these activities and practices are as follows: 1) teaching methods, or how information is disseminated and learning is accomplished during class; 2) pedagogical moves, pertaining in part to teaching style and strategy; 3) questioning between instructors and students; 4) cognitive engagement by students, such as problem solving; and 5) instructional technology usage. The developers of the TDOP have used both a five-minute and a two-minute window and initially reported inter-rater reliability using the five-minute window [49]. Based on personal communication with the developer of the TDOP, the two-minute window provides more granular data, as more happens during a five-minute period of time versus a two-minute period. However, the two-minute window places more demands on the observer and may decrease his/her ability to record notes and casually and comprehensively assess classroom happenings and the environment [50].

When we were able to collect pre-flip observation data, we assessed changes (pre-flip to flip) in the occurrence of certain behaviors of interest, such as student dialogue or problem solving, using Fisher's Exact test. For those courses in which we were not able to collect pre-flip data, we compared our results to those of a recent TDOP study of 58 STEM classrooms to measure the relative amount of active and interactive learning in our flipped classrooms. Either one or two trained observers performed the classroom observation using the TDOP. When two observers performed the observation, they discussed any differences in assigned codes afterwards until a consensus was reached. Our overall inter-rater reliability statistic for use of the TDOP was Cohen's κ=0.86, with the five dimensions ranging from 0.70 to 0.92. Values of κ above 0.75 suggest strong agreement beyond chance; values between 0.40 and 0.75 indicate fair levels of agreement above chance [51]. These statistics are based on a total of 80 five-minute observation segments across four different courses.

College and University Classroom Environment Inventory (CUCEI)

We distributed the classroom environment survey, formally known as the College and University Classroom Environment Inventory (CUCEI), to the students at approximately the two-thirds mark of the semester. This instrument reliably evaluates seven psychosocial dimensions of the classroom and has been used previously in flipped classroom research [6, 52]. Several of the dimensions are particularly relevant to the flipped classroom, including involvement, student cohesiveness, individualization, personalization, and innovation. There are seven questions per dimension, and each question has a scale of 1 to 5, with 5 being most desirable. For those courses in which we were able to collect pre-flip environment data, we assessed changes in the classroom environment using t-tests and Cohen's d effect size calculations. The effect size represents the extent of the difference between two groups. Cohen defined effects as small (d=0.20), medium (d=0.50), or large (d=0.80) [53].

Flipped Classroom Evaluation Survey

We also administered the flipped classroom evaluation survey at the two-thirds point of the term to assess student attitudes towards and perceptions of the flipped classroom, including benefits and drawbacks perceived. Our flipped classroom evaluation survey was modeled upon the work of Leicht, Zappe and colleagues, who used student perception instruments in a flipped course with Penn State undergraduates having sixth-semester standing in architectural engineering [5, 7]. We extended this survey via input from our own faculty. A trained coder, who was a junior engineering student, conducted a content analysis of the open-ended questions on benefits and drawbacks perceived. A second coder, who was the assessment analyst for the project, served to establish inter-rater reliability by coding a sample (i.e., approximately 30%) of the responses [54]. The frameworks used for the coding were developed by the assessment analyst based on a grounded, emergent qualitative analysis of all student responses [54]. The inter-rater reliability scores achieved based on Cohen's Kappa were $\kappa = 0.75$ for the benefits analysis and $\kappa = 0.83$ for the drawbacks analysis.

Assessment of Learning and Achievement

To assess achievement in the flipped classroom, we compared direct assessment data, including homework and exam scores, between the pre-flipped and flipped versions of the course using an analysis of covariance with the pre-course cumulative GPA or SAT score as the covariate, or control variable. Pre-flipped versions of the course had been taught in previous semesters. The instructors were also interviewed after the course to discuss gains and outcomes that may not have been apparent in the direct assessment results. Finally, to understand the relationship between preparation and achievement in the flipped classroom, we performed a correlational analysis between the number of videos accessed and the final course grade. The number of videos accessed was based on web analytics data.

RESULTS

As discussed, we performed a variety of assessment activities to evaluate the effectiveness of our flipped classroom initiative and to address our research questions. We used the structured classroom observation and the classroom environment survey to address question 1 regarding student engagement during class and the classroom environment. Exam and homework results (pre-flip versus flip), instructor interviews, and a correlational analysis of video usage and course grades were used to investigate question 2 about the impact of the flipped classroom on achievement and learning of course content. With our flipped classroom evaluation survey, we identified students' perceptions of the benefits and drawbacks of the flipped style to investigate question 3. Based on a review of the literature, we also provide a comparison of our implementation to other flipped implementations nationally.

RQ1: Student Engagement During Class: Observation

Structured observation of our flipped classrooms using the TDOP was conducted to evaluate student engagement and involvement during class. We were also able to observe two of the courses before they were flipped. A quantitative and qualitative description of each classroom based upon this observation is provided in this section. Table 4 displays the percentage of five-minute observation segments in which each classroom element of interest was observed for each course. In addition, we compared four of our flipped courses against a national 2012 TDOP study that used two-minute observation windows for lecture sessions of STEM classes. The courses in Table 4 are those for which we did not have pre-flip observation data.

Flipped Classroom Descriptions and Comparison to National TDOP Study

Bio-thermodynamics: Our bio-thermodynamics course was characterized by a large amount of instructor-to-student interaction as well as interaction among the students. The instructor circulated during 82% of the five-minute observation segments (MOV) as he frequently posed questions. His style was very interactive; he persisted until he received answers to his questions. The students worked in small groups (SGW) and discussed course content (ART) in 66% of the segments. These discussions centered on problem solving efforts (PS), divergent responses to challenging clicker questions (CL), or team quizzes (A).

Chemical Engineering Dynamics, Modeling and Control: In the chemical engineering course, there was a large amount of student activity and interactivity. In 65% of the segments, students actively discussed course material (ART). The students solved problems in 44% of the segments (PS), often working individually and/or with software at the desk (DW) while assisting one another. At other times, the students specifically worked in small groups (SGW) on their class projects or to resolve disagreements on a clicker question. This was complemented by the instructor and TAs circulating (MOV) to provide support as the students asked questions or sought help (SCQ) in 37% of the segments. Assessment (A) was accomplished using clickers (CL).

Freshman Programming: The freshmen programming class was also characterized by a large amount of active student work, although it was very active even before flipping the course. In 56% of the segments, students actively worked at the desk (DW) with MATLAB or C. This was often accompanied by instructor demonstration of coding tasks from the podium computer. Active problem solving (PS) with discussion among the students (ART) occurred in 40% and 32% of the segments, respectively. This was complemented by the instructor and TA circulating among the students (MOV), typically to provide help, in 45% of the segments. Student questioning to seek assistance (SCQ) occurred in 47% of the segments, which was likely encouraged by the circulation of the instructor and TA. Students actively worked on assessment quizzes in 32% of the segments; the quizzes involved analyzing or writing code during class. The students were specifically asked to work in small groups in 29% of the segments. During the fall 2014 semester, the students were asked to practice coding (in small groups) during class more than ever before, which was enabled partly by switching to coding-based quizzes. Thus, our freshman programming class has become more hands-on and aimed at providing needed programming experience for students.

Mechanical Engineering Design: The mechanical engineering design course represented an outstanding implementation of the flipped classroom. In short, the teaching assistants were in nearly constant demand during class and provided as-needed support to the students' use of SolidWorks. Specifically, in 97% of the segments, the TAs circulated to provide support (MOV) and answer the students' questions (SCQ). During nearly the entire class period, students actively worked with SolidWorks at their desks (DW) to solve the design problem (PS) posed to them. These problem assignments were generally due at the end of the two-hour period. At the same time, the students discussed the work and assisted one another (ART).

TDOP Comparison Study: The national TDOP study was based on lecture-based classrooms and as such does not provide a benchmark per se for our active, flipped classrooms. However, the national study does provide some perspective and a point of reference for our observation results. As can be seen in Table 4, our flipped classrooms were active and interactive compared to those in the TDOP study. The national study occurred with of 58 math and science faculty in three public research universities and involved 38% upper and 62% lower division offerings [55].

Each element in our flipped classroom that was very significantly higher compared to the national study with $p<0.0001$ is marked with an asterisk (*). These elements would also remain significant after correcting for multiple comparisons using Bonferroni's adjustment [56]. This demonstrates that flipped instruction drives student engagement and involvement in learning and was successful in promoting better utilization of our instructional facilities designed for team-based active learning. Similar to the national TDOP study, Finelli and Daly also noted a small number of classroom observation segments (i.e., 9%) that involved active learning when assessed across 26 engineering courses using a variation of the TDOP [57].

In a personal conversation with one of the developers of the TDOP, he pointed out that it's possible a five-minute observation window could result in higher percentages compared to a two-minute window in certain cases [50]. For example, if problem solving (PS) was observed just once in ten minutes using the two-minute observation window, its frequency of occurrence would be 20%.

Practices Observed		% of Observation Segments				
Classroom Element	Description	STEM Comparison Study	Bio Thermo Dynamics	Chemical Engineering Dynamics/ Modeling	Freshman Programming	Mechanical Engineering Design
MOV	Instructor circulates in classroom	**7%**	82%*	37%*	45%*	97%*
SGW	Small group work/discussion	**9%**	66%*	21%	29%*	
ART	Student articulation/discussion	**9%**	66%*	65%*	32%*	86%*
PS	Problem solving	**12%**	34%*	44%*	39%*	97%*
CL	Use of clickers	**5%**	30%*	14%		
A	Assessments (quizzes)	**5%**	28%*	14%	32%*	
SCQ	Students ask question or request assistance	**9%**	23%	37%*	47%*	97%*
DW	Students actively work at desk/PC	**6%**		44%*	56%*	98%*

$*p < 0.0001$

Table 4. Comparison to 2012 National STEM TDOP Study (Two-Minute Window).

However, using the five-minute window, the frequency of occurrence would be 50%. Granted, in this case, problem solving (PS) occurred rather sparsely during the ten minutes. If PS had occurred continuously during the ten minutes, then the frequencies of occurrence would have been the same at 100%. In the flipped classroom, our students often worked for a substantial period (i.e., longer than two minutes at a time) on problem solving in groups or individually with student discussions taking place. Nonetheless, we obtained earlier comparison data from the developer of the TDOP, in which a five-minute observation window had been used. This data was collected during the spring of 2010 and involved 57 math and science instructors at three large research universities [49]. We used this data as a second comparison, as shown in Table 5. However, the developer cautioned that the TDOP was at an early stage of development when he used the five-minute window and was a much different protocol compared to the present instrument. Since several of the codes in Table 4 did not exist in the earlier protocol, we could only compare certain elements, such as SGW, PS, CL, and DW. Thus, while comparing our five-minute-window results against the two-minute-window study was not optimal as described, a comparison using the earlier five-minute-window study was likewise difficult, given the differences with the current instrument.

In comparing tables 4 and 5, the most notable difference was related to the problem solving (PS) element. Using the five-minute comparison window as shown in Table 5, the comparisons of the Bio-thermodynamics and Chemical Engineering courses did not represent significant differences, although they did with the two-minute window comparison in Table 4. However, based upon either

Practices Observed		% of Observation Segments				
Classroom Element	Description	STEM Comparison Study	Bio Thermo Dynamics	Chemical Engineering Dynamics/ Modeling	Freshman Programming	Mechanical Engineering Design
SGW	Small group work/discussion	**5%**	66%*	21%	29%*	
PS	Problem solving	**31%**	34%	44%	39%	97%*
CL	Use of clickers	**6%**	30%*	14%		
DW	Students actively work at desk/PC	**5%**		44%*	56%*	98%*

*$p < 0.0001$

Table 5. Comparison to 2010 TDOP Study (Five-Minute Window).

the two-minute or five-minute comparison study, our flipped classrooms exhibited a large degree of active learning and student interaction, illustrating what is possible with a flipped classroom.

Pre-Flipped vs. Flipped Classroom Observation

Statics/Mechanics: Statics/Mechanics was one of the two courses we were able to observe before it was flipped. The pre-flip statics course did not contain elements of active learning, such as small group work (SGW), student discussion (ART), or problem solving (PS), as shown in Table 6. However, in the flipped course observed multiple times between the fall of 2013 and the fall of 2014, a change occurred in active learning, as shown in the table. The values for the flipped classroom are an aggregation of the data collected over all four semesters. The level of interactivity also increased, with a greater percentage of segments containing student questions or requests (SCQ), instructor

Practices Observed		% of Observation Segments		
Classroom Element	Description	Pre Flip	Flip	Difference p
ART	Student articulation/discussion	0%	42%	0.007
SGW	Small group work/discussion	0%	42%	0.007
MOV	Instructor circulates in classroom	0%	41%	0.013
SCQ	Students ask question or request assistance	0%	36%	0.029
PS	Problem solving	0%	35%	0.029
A	Assessments (quizzes)	0%	11%	0.594

Table 6. Pre Flip vs. Flip Observation for Statics/Mechanics.

circulation (MOV), and student discussion (ART). Team quizzes were also given (A); they were a form of active learning and a means to drive accountability with the videos.

This course actually evolved over time in terms of the ideals of the flipped classroom. During the first flipped semester, the number of segments containing small group work (SGW) and student discussion (ART) as the instructor circulated (MOV) was low at 10%. During the second semester, these elements each occurred in 47% of the segments, while problem solving (PS) occurred in 29%. By the third semester, all four of these key elements each occurred in 64-67% of the observation segments. During the fourth semester, the percentages were not as high as during the second or third semesters but higher than in the first semester.

We compared the pre-flip to the flip percentages in Table 6 using Fisher's Exact test; Fisher's test can be used in lieu of a z-test of proportions when the numerators are small. The increases in ART and SGW were the most significant ($p<0.01$) and would remain significant at $\alpha=0.05$ if corrected for multiple comparisons using Bonferroni's adjustment.

Facility Layout: In the pre-flipped facility layout course, problem solving (PS) with student dialogue (ART) each occurred in only one of the observation segments (7%), indicating the opportunity for increased active learning. This opportunity was met by flipped instruction, with problem solving and student dialogue each occurring in 56% of the segments. This was complemented by the instructor and TA circulating to provide assistance (MOV), which occurred in 63% of the segments. Student questions and requests (SCQ) increased from 13% to 56%, which was likely encouraged by the circulation. Based on Fisher's Exact test, the most significant increases were in instructor circulation among the students, problem solving, student discussion as shown in Table 7; these would remain significant at $\alpha=0.05$ if corrected for multiple comparisons.

The increases within our statics/mechanics and facility layout courses (pre-flip to flip) in student discussion (ART), small group work (SGW), problem solving (PS), and instructor circulation (MOV)

Practices Observed		% of Observation Segments		
Classroom Element	Description	Pre Flip	Flip	Difference p
SCQ	Students ask question or request assistance	13%	56%	0.023
PS	Problem solving	7%	56%	0.006
ART	Student articulation/discussion	7%	56%	0.006
MOV	Instructor circulates in classroom	0%	63%	0.0002

Table 7. Pre Flip vs. Flip Observation for Facility Layout.

to answer questions and provide help illustrate the impact that flipped instruction can have on the engagement, interactivity, and student involvement in engineering classrooms.

RQ1: Flipped Classroom Environment: Environment Survey

It is very important to understand students' perceptions of their experiences in the classroom and the psychosocial environment in which they learn in addition to assessing their performance [62]. To this end, we assessed the psychosocial dimensions of our flipped classroom as defined in Table 8 using the College and University Classroom Environment Inventory (CUCEI). We received a total of 793 responses from students in our six flipped courses between fall 2013 and fall 2014 (inclusive), representing a 43% response rate. Across these courses, the personalization dimension scored the highest of the seven dimensions, with a dimension mean of 3.88 on the five-point scale, with a score of 5 being most desirable. This dimension relates to the interaction between the students and their instructor and is thus a perceived strength of the flipped classroom. This is a good outcome for the flipped classroom, as Astin's large-scale correlational study of over 20,000 students found that frequent interaction between faculty and students was critically important to student development and satisfaction [58-59].

Dimension	Definition	Pitt Engineering Flipped Courses	Statistics Flipped Course	Chemistry Tutorial Course
		M	*M*	*M*
Student Cohesiveness	Students know & help one another	3.04	3.00	2.87
Individualization	Students can make decisions; treated individually or differentially	2.64	2.58	2.59
Innovation	New or unusual class activities or techniques	2.99	3.08	2.84
Involvement	Students participate actively in class	3.29	–	3.03
Personalization	Student interaction w/ instructor	3.88	4.13	3.26
Satisfaction	Enjoyment of classes	3.39	–	3.40
Task Orientation	Organization of class activities	3.74	3.51	3.31
	n	**793**	**23**	**257**

Pitt *SD* values: Cohesiveness 0.804; Individualization 0.475; Innovation 0.565; Involvement 0.633; Personalization 0.752; Satisfaction 0.915;Task Orientation 0.661
Statistics *SD* values: Cohesiveness 0.71; Individualization 0.56; Innovation 0.60; Personalization 0.75; Task Orientation 0.69
Chemistry *SD* values: Cohesiveness 0.90; Individualization 0.62; Innovation 1.02; Involvement 0.57; Personalization 0.70; Satisfaction 0.78; Task Orientation 0.70

Table 8. CUCEI Comparisons.

In a post-course interview, our bio-thermodynamics instructor shared that in his flipped classroom, students were less hesitant to interact with him and ask questions during class. The individualization and innovation dimensions scored lowest and below the average value of 3.00, with dimension means of 2.64 and 2.99, respectively. Thus, our respondents did not perceive notable individual or differential treatment or innovative techniques, which are two key goals of flipped instruction; thus, these dimensions may represent opportunity areas. An internal consistency reliability analysis of our flipped classroom environment data showed Cronbach's alpha reliabilities above or near 0.70 for five of the seven dimensions [60].

Comparison to Other Classroom Environments

We had the goal of comparing our flipped classroom environment data against a large-scale study, as we had done with the TDOP data. However, based on a search of the literature and personal communication with the developer of the CUCEI, we were unable to identify such a study [61]. The developer of the CUCEI had recently completed a literature review on classroom learning environments discussing over 40 years of research with STEM classrooms [62]. However, we did find two smaller-scale CUCEI studies involving courses with similar classroom formats. Compared to a flipped statistics course at another US university, our courses compared closely, as shown in Table 8. Although the CUCEI instrument used at this other university differed somewhat from Fraser's original instrument, we determined the questions to be sufficiently similar and suitable for comparison [6, 63]. Also, two of the dimensions in Fraser's instrument – satisfaction and involvement - were not measured in the statistics study. Although three of our dimension means were higher, all five means were statistically equivalent between the two schools based on a t-test. This was likely influenced by the small sample size at the other school. A non-parametric test would have been preferable; however, we had only summarized (i.e., mean) data from the statistics study. From a takeaway perspective, Personalization was also rated highest in the statistics flipped classroom, while Individualization was also the lowest rated dimension. This may be a general result for flipped classrooms. A second, larger CUCEI study was performed on a chemistry tutorial class at the University of the South Pacific [64]. This tutorial class was similar to our flipped classroom in that it was an interactive class in which students had the chance to clarify lecture content and develop scientific problem solving skills under guidance. Our flipped classroom environment was significantly better on five dimensions – involvement, personalization, and task orientation ($p<0.0001$) as well as student cohesion and innovation ($p<0.005$). Thus, we compared favorably to this chemistry course having a similar class format. Standard deviations are provided so that comparisons can be run by others who may wish to use this instrument in a flipped classroom.

Comparison of Pre-Flipped and Flipped Environments

We were able to collect pre-flip environment data for two courses, given the timing of the initiative, and thereby compare these courses in a pre-flip to flipped manner.

Statics/Mechanics: In the statics course, four of the seven CUCEI dimensions showed a significant increase ($p<0.0005$) pre-flip to flip based on t-tests. These four significantly improved dimensions are of key interest to our program evaluation because they are general goals of a flipped classroom – individualization, personalization, involvement, and student cohesiveness. Among the significantly improved dimensions, individualization was associated with the largest effect size ($d=0.96$), although students rated it lowest among the seven dimensions in the flipped classroom. Thus, improvement was actually greatest for the individualization dimension. Personalization, involvement, and cohesiveness had effect sizes of $d=0.95$, 0.85, and 0.83, respectively.

Facility Layout: In the flipped version of the facility layout course, there was a significant increase in three of the dimensions based on t-tests – individualization ($p<0.0005$), personalization ($p<0.0005$), and involvement ($p=0.002$). Upon adjusting for multiple comparisons using Bonferroni's correction, we considered innovation *not* to be significant ($p=0.021$). Cohen's d was found to be large for individualization ($d=2.01$) and personalization ($d=1.06$) and medium for involvement ($d=0.67$). In his post-course interview, the facility layout instructor noted there was definitely increased opportunity to interact with students during a flipped class (as anticipated), and this coincides with the significant increase in the personalization dimension. However, in the instructor's viewpoint, even more interaction would have been possible if additional teaching assistants had been available during class.

RQ2: **Achievement and Learning: Direct Assessments and Instructor Interviews**

We directly assessed the impact of the flipped classroom on student learning and achievement using examples of student work that offered the best comparison by virtue of being the same or nearly the same in the pre-flipped versus flipped versions of the course. Depending on the course, these included exams or homework assignments. The instructors for each course remained the same over the various semesters considered. Below, we provide direct assessment results from four courses, which are summarized in Table 9.

Introductory Engineering Programming

For our freshman programming course, we compared results of the midterm and finals exams in the pre-flip vs. flipped courses in the sections in which the videos were emphasized by the instructor. In the honors variant of the course, which is taught in the fall semester to first-time freshmen, we found an increase in the average midterm score (pre-flip to flip) from 86% to 87%. This was based on two semesters of pre-flip ($n=109$) and two semesters of flip ($n=150$) data. With the final exam,

Course	Direct Assessment	Significant Difference (α=0.05)
Introductory Engineering Programming	Exam (Midterm & Final)	No
Intro to Mechanical Engineering Design	Homework (SolidWorks Assignments)	No
Bio-thermodynamics	Exam (4 Topic Areas)	Yes
Facility Layout/ Material Handling	Homework (Facilities Location Problem)	Yes

Table 9. Direct Assessments Summary.

there was also an increase in the average from 86% to 87%. This was based on two semesters of pre-flip (n=109) and two semesters of flip data (n=150). As a baseline comparison of the pre-flip vs. flipped honors groups, we examined the Math SAT score and the first-term cumulative GPA. This was an end-of-term GPA but was the first (U. of Pittsburgh) GPA available to us. The Math SAT score served as a pre-course variable. We found the average first-term GPA to be higher for the flip group, although not significantly so (p=0.14), and there was no significant difference in the Math SAT scores between the groups (p=0.82). We ran an analysis of covariance (ANCOVA) with each of these variables as covariates, or control variables. For the midterm exam with GPA as the covariate, the difference (pre-flip to flip) was not significant (p=0.61). The same was true using Math SAT as the covariate (p=0.13). For the final exam, with the first-term GPA as the control variable, the difference (pre-flip to flip) was also not significant (p=1.00). In addition, with Math SAT as the control, the difference in final exam scores was not significant either (p=0.29).

For the non-honors variant of the freshman programming course, which is taught in the spring semester of the freshman year, we analyzed two semesters of non-flip (n=421) and one semester of flip data (n=232), based on the data that was available to us. The pre-course cumulative GPA was used as a covariate in a pre-flip to flip comparison of the midterm and final exam scores. There was an increase in the midterm score (pre-flip to flip) from 83% to 84%, which showed some evidence of a significant change (p=0.056) based on the ANCOVA results. With the final exam, there was a decrease (pre-flip to flip) from 80% to 79%, which was not significant (p=0.56) based on the ANCOVA results. The pre-course cumulative GPA was slightly lower (although not significantly so) for the flipped-classroom students.

Mechanical Engineering Design

In the introductory mechanical design course, we compared students' achievement on their SolidWorks take-home assignments using one semester of pre-flip and two semesters of flip performance data. Using pre-course cumulative GPA as a covariate or control variable, we did *not* find a significant difference pre-flip to flip (p=0.41). The pre-flip percentage was 94% (n=177); the flipped percentage was 93% (n=394). The SolidWorks take-home assignments were generally the same between the semesters. The average cumulative GPA for the pre-flip group was just slightly higher, although not significantly so.

Despite the statistical equivalence of the two sets of SolidWorks performances, the instructor reflected that the students in the flipped section were more "sophisticated" and proficient CAD users. He attributed this to the practice time available with SolidWorks in the flipped classroom - students had to solve twice as many problems versus in the non-flipped course. In addition, the instructor also noted in both a post-course interview and a focus group that students likewise felt more proficient and confident with SolidWorks versus in previous years. Others have reported increased student confidence and self-efficacy as well [65]. For the first time in teaching this course, his students identified SolidWorks as the best part of the course.

Bio-thermodynamics

In our bioengineering course, a comparison of exam results in the flipped semester versus in the prior four (non-flipped) semesters uncovered significant improvements. The pre-course cumulative GPA was used as a covariate in the comparison. In an exam covering four topic areas, students in the flipped class performed better on all four topics – concept mastery (p=0.004), conservation of mass (p<0.0005), conservation of energy (p<0.0005), and gas expansion (p<0.0005). The latter two topics were associated with large effect sizes, with Cohen's d values of 0.87 and 0.98, respectively. The first three topics had pre-flip vs. flipped sample sizes of 224 and 87, respectively; the fourth topic had sample sizes of 167 and 87, respectively. As a comparison of the two groups (pre-flip vs. flipped), the average pre-course cumulative GPAs were not significantly different, with the average for the pre-flip group just slightly higher (p=0.33).

Prior to flipping, the instructor did not have time during class to be as interactive with the students or as persistent in receiving answers to his questions. He felt this was a large contributor to the statistically higher scores on the exam, as expressed during an interview. In addition to this outcome, the instructor expressed in an interview that the students in the flipped course were much better problem solvers than in prior years. In the flipped course, the students had the opportunity to solve more problems; in fact, the students were assigned higher-level problems in the flipped course and solved them or made great strides in doing so, based on the instructor's reflection. Based on these results, he plans to provide better, more challenging problems to the students going forward. In the instructor's assessment, the flipped classroom was overall a good experience for him and the students; in fact, he believes he benefitted because it gave him insight into the types of problems he should be providing to students.

Facility Layout/Material Handling

We compared the results of a facilities location homework assignment in the pre-flip versus flipped courses. This homework problem remained the same across the semesters. The pre-flip average was based on three semesters of data (n=155), and the flipped average was based on two semesters (n=148). The instructor pilot-flipped a few course topics in the semester prior to full implementation; thus, we had two semesters of flipped data. Using pre-course cumulative GPA as a control variable, we found a significant improvement from the pre-flipped to the flipped course, with average scores of 81% versus 89%, respectively (p<0.0005). The effect size was medium at d=0.44. As a comparison of the two groups, the pre-course cumulative GPAs were not significantly different between the pre-flipped and flipped groups, with the average GPA for the "flipped" group just slightly higher (p=0.37).

Analysis of Video Usage Data

We analyzed web analytics data from fall 2013 through fall 2014 to determine the number of videos accessed by each student. This data was a direct assessment of their participation in and preparation with flipped instruction. We were also interested in the relationship between their preparation and achievement in the flipped classroom. Unfortunately, the web analytics data has a limitation in that it indicates that a video was accessed or launched and not necessarily that it was watched in whole or even in part. In addition, students might have watched the videos in groups in the dormitories; therefore, not all students might have officially logged in to watch a particular video. The sophomore through senior students appeared to have demonstrated some responsibility for the self-directed portion of the flipped classroom; however, it appears the freshmen did so to a much lesser extent. Based on our experiences, freshmen may require additional monitoring with the flipped classroom. Unfortunately, for the bio-thermodynamics course, the web-based data was collected in a different manner and could not reliably be combined with data from the other courses; therefore, the bioengineering course data is not reflected in Table 10.

	Average %	n (students)
Freshmen	15%	381
Sophomores through Seniors	60%	784

Table 10. Web Analytics Percentage of Videos Accessed.

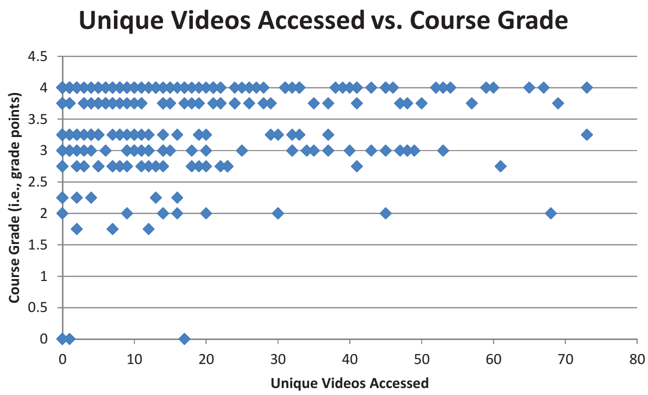

Figure 1. Videos Accessed vs. Final Course Grade (Freshmen).

For each of the sophomore, junior, and senior-level courses (excluding the bioengineering course), we found correlations between 0.36 and 0.43 for the number of unique videos accessed and the final course grade (i.e., grade points associated with the final grade). These were significantly different from zero ($p<0.001$). This suggests some relationship between preparation and achievement in the flipped classroom. However, even for freshman in those sections in which video watching was emphasized by the instructor, this correlation was only 0.01 and not significantly different from zero. For this subset of freshmen, the scatter plot of the unique videos accessed (out of a possible 79) versus the grade points associated with the course grade is shown in Figure 1. This plot shows that a small number of freshmen did in fact "fit" the expected relationship between videos accessed and the final course grade. However, many students who performed well accessed only a portion of the available videos, as indicated by the large number of points near the upper left portion of the plot. This raises several questions for future research. For those students who were not accessing the videos but still performing well, how did they acquire their knowledge? What are the primary methods, behaviors, or characteristics of freshmen who do not fit the expected relationship between video usage and achievement in the flipped classroom?

Thus, our preliminary findings suggest continued research in this area, including investigation of the factors that contribute to the low correlation between video usage and course performance for freshmen, such as differences in student learning styles, base knowledge, other support or social structures, and instructor characteristics. An additional research question of interest is the following: when in the students' undergraduate careers do they begin to take greater responsibility for watching the videos as part of the self-directed portion of the flipped classroom?

In addition, we also analyzed the total number of times the videos were accessed versus the final grade and found the correlations to vary widely by course. This analysis accounted for the cases in which a video was accessed multiple times by students, for example for reinforcement or study purposes. The correlation for the freshman "emphasis sections" in which video watching was emphasized was again low at 0.02 and not significantly different from zero. The correlations for each of the sophomore and junior courses (excluding bio-thermodynamics) ranged from 0.19 to 0.33. Surprisingly, the correlation for the seniors was -0.01 and not significantly different from zero. We defined a "distinct" access of a video as one that occurred at least ten minutes after the last access of the video by the student. For example, if a student accessed a particular video at both 2:05 PM and 2:07 PM on a given day, these would *not* be counted as two distinct accesses. We considered ten minutes to be reasonable given the average length of the videos.

Although we collected web analytics data on video usage, we also asked the respondents to self-report the percentage of videos they watched, given the limitations in the web analytics data (previously discussed). Compared to the web analytics data, the self-reported data indicate higher video access percentages. However, even in those freshmen course sections in which video watching was emphasized by the instructor, the average percentage reported was markedly lower than the percentages reported by the sophomores through seniors, as shown in Table 11. Based on a t-test, the freshmen watched a significantly lower percentage of videos in comparison ($p<0.0005$). The percentage reported by Penn State upper-level engineering students provides a second point of comparison. Despite some differences in emphasis across the freshman sections, all freshmen were directed to watch the videos via the course syllabus and website. This indicates freshmen students' lack of responsibility in preparing for their flipped classes. However, some lecturing still occurred in our freshman flipped classes with coding demonstrations by the instructor. This may have impacted the level of video watching. Ninety-four percent (94%) of responding freshmen from the sections in which the videos were emphasized indicated they watched the videos *after* the class period for which they were assigned; only 11% used the videos for first-time instruction as intended. In addition, starting in the spring 2014, we asked freshmen about previous programming experience. Interestingly,

	Average %	n (students)
Freshmen	45%	95
Sophomores through Seniors	77%	321
Zappe et al. (Penn State)	92%	77

Table 11. Self-Reported Percentage of Videos Watched.

only 29% of respondents from the "emphasis sections" were familiar with programming prior to the course. Therefore, video watching would seem to have been warranted by these students; however, this did not occur *prior to* class for the most part.

***RQ3*: Perceptions of Benefits and Drawbacks: Flipped Classroom Evaluation Survey**

The students were asked to evaluate the flipped course via a survey designed to provide both formative and summative feedback. Approximately 29% provided feedback between the fall of 2013 and the fall of 2014. One of the questions we asked was "Do you prefer a flipped classroom over a traditional lecture class?" The distribution of student responses showed an approximate three-way split, with 27% responding yes, 36% responding no, and 36% being unsure. Our seniors, with whom we experienced some resistance, responded definitively "no" in 56% of the cases. We compared the proportion of seniors who responded "no" to all other respondents who said "no." Although not statistically significant based on Fisher's Exact test, the result may provide some preliminary evidence concerning seniors' preferences for the flipped classroom (p=0.12). In a related question, when asked to compare the use of class time for problem solving or active learning with the instructor present versus listening to a lecture, 57% of all respondents preferred the former. For the seniors, this percentage was only 31%. A test of proportions (based on Fisher's) for seniors vs. non-seniors who preferred in-class active learning was associated with p=0.04. In comparison, Zappe et al. found a value in between these percentages, with 48% agreeing or strongly agreeing that they preferred problem solving versus lecture during class time [7].

Content Analysis of Benefits and Drawbacks

In an open-ended question on the evaluation survey, we asked the students what they liked about the flipped classroom and its benefits. The frequencies associated with the categories in our coding framework are shown in Table 12. The most frequently mentioned benefit as perceived by 44% of student respondents related to conveniences afforded by video or online learning, including the ability to re-watch videos, self-pacing, flexibility, and accommodation of one's own preferences. This was followed by enhanced or deeper learning, as mentioned by 31% of respondents; this category included better understanding and learning, enhanced effectiveness or depth, multiple resources for understanding material, and reinforcement and review of material. There were 10% of respondents who identified benefits such as higher engagement, better class preparation, and the promotion of professional behaviors. This was also a welcome finding. These results were based on a content analysis of 389 student responses by a single coder, who was an upper-division undergraduate engineering student. A second coder, who was the assessment analyst for the project, coded 30% of the responses, corresponding to 118 responses, to provide a measure of inter-rater reliability. The

Frequency	% of Respondents	Category	Description
171	44%	Video/Online Learning	Re-watch videos Work at one's own pace; pause video Flexibility, convenience, own preferences Modularization of topics
121	31%	Enhanced Learning or Learning Process	Better understanding; less confusion Enhanced learning/effectiveness/depth/ability Subject matter retention Multiple sources/resources for understanding Reinforcement and review Multiple attempts
98	25%	Alternative Use of Class Time	In-class active learning, problem solving, clickers In-class support and questions In-class group time for projects Student interactivity and peer support
59	15%	Specific to Course or Videos	Videos concise or had a good pace Overall work time less Videos had relevant content (e.g., demo or examples) or were of high quality
37	10%	Preparation, Engagement & Professional Behaviors	Engaged during class; paid attention; not bored Enjoyed class Arrived to class prepared Ability to learn on one's own; independence Drove motivation and accountability
30	8%	No Benefit or Neutral Result	No benefits perceived Did not like flipped instruction Videos not used Instructional differences not noticed

Table 12. Summary of Open-Ended Responses to Benefits.

inter-rater reliability score based on Cohen's Kappa was κ = 0.75, which suggests good agreement beyond chance [51].

In a second open-ended question, we asked the students what drawbacks they perceived with the flipped classroom and their suggestions for improvement. The same undergraduate engineering student performed a content analysis of 356 student responses. As shown in Table 13, the most frequently mentioned drawback or suggestion involved feedback specific to the particular instructor or his videos, such as "include more examples in the video" or "videos did not have an appropriate pace." This was followed by suggestions regarding the use of in-class time with the flipped classroom (27%) and requests to better prepare, equip, and incentivize students for this new method of instruction (17%). Twelve percent of respondents noted increased burden, load, and stress with the flipped classroom. We were encouraged to learn that very few respondents (2%) indicated decreased learning, and only 9% recommended or wanted a different teaching approach. As with the analysis of the benefits, a second coder, the assessment analyst for the project, coded 32% (n=114) of the

Frequency	% of Respondents	Category	Description
136	38%	Specific to Course or Videos	Include more examples or problems in the videos Videos needed editing or bug/technical fixes Videos were too long Videos were not sufficiently described Videos were dry or boring Videos did not have an appropriate pace Videos repeated information Video material was too complex
97	27%	In-Class Time	Increase time for active learning or problem solving Increase effectiveness or relevancy of problems; grade them Provide appropriate amount of lecture or content review Have more instructor-types during class to assist Synchronize class activity and video content
59	17%	Prepare, Equip & Incentivize Students to Flip	Prepare students for the flipped learning method Incentivize students, including video quizzes Clarify/emphasize expectations, including video watching Provide video "lecture" notes Ensure videos available in advance for students
55	15%	No Drawbacks or Neutral Result	No drawbacks or suggestions
42	12%	Load, Burden, Stressors	Insufficient time to complete out-of-class activities Increased work load Increased time burden Concerns over grades or impacts to the grade Accountability quizzes (including surprise)
31	9%	Approach Differently	Do not flip courses in general; use traditional teaching Do not flip this course in particular Provide students with a choice on flipping Flip only a portion of the class periods
18	5%	Video/Online Learning	Students unable to ask questions during a video Instructor unable to sense student understanding in a video Distractors to viewing videos in a non-classroom setting Less motivation to attend class
8	2%	Student Learning	Lesser understanding or learning Difficulty learning from a video

Table 13. Summary of Open-Ended Responses to Suggestions/Drawbacks.

responses to provide a measure of inter-rater reliability. The inter-rater reliability score based on Cohen's Kappa was $\kappa = 0.83$, which suggests strong agreement beyond chance [51].

DISCUSSION

Our direct assessment results involving exam and homework scores for flipped versus non-flipped instruction across our various courses were mixed. This coincides with other studies in the literature, as discussed the literature review section. In addition, our indirect assessment results indicate, as do others from the literature, that some students prefer the flipped classroom while others do not. For example, 54% of the North Dakota mechanical engineering students preferred the flipped format [23]. This was higher than our aggregate result in statics and introductory mechanical design, with 32% preferring the flipped format. Similar to others who have flipped courses, our mechanical design instructor noted in his post-course interview that some students were dis-satisfied with the lack of "live" lectures [23]. Based on this, he gave a small amount of "live" lecture on SolidWorks during the subsequent semester, and he planned to do more, as the students were appreciative. Likewise, based on his post-course interview, our senior instructor planned to deliver upfront mini-lectures in future implementations of his course, in part because many students came to class not knowing how to engage with the problems. Others have considered this same approach [30, 66]. There have also been mixed reports in the literature of freshman preferences for the flipped classroom. Only 22% of our freshmen preferred the flipped classroom. The remainder was equally split between "do not prefer" and "unsure of my preference." With flipped first-year engineering courses, a low level of classroom preparation is another theme that has been discussed in the literature [41, 67]. Similarly, our freshmen did not use the videos for first-time instruction as intended. Our instructors hoped to instill in the freshmen a tendency to arrive to class prepared to use their skills and ask questions - versus arriving with the expectation of being "given" information.

We feel that our freshmen did not take responsibility for their class preparation and instead expected to "be taught" during class. We believe freshmen may not have the maturity to carry out the flipped style of instruction as fully as intended, including an inability to manage time well. However, in the viewpoint of our freshmen instructor and program director, this does not preclude the desirability of introducing freshmen to the flipped method. Given these maturity issues, though, it may not be desirable to flip the entire freshman curriculum. One of his hopes was to promote behavioral changes in freshmen, including teaching them "how to learn" and research problems initially on their own. He felt that students must be exposed to flipped instruction often during their undergraduate careers for it to have a deep impact; thus, flipping should be a school wide initiative. This sentiment coincides with the viewpoint of our senior-course instructor, as will be discussed. Thus, preparing freshman as well as all students for the expectations of the flipped classroom is a necessary first step.

One of the predominant themes noted by the instructor of our senior-level chemical engineering course was student resistance to and dissatisfaction with flipped instruction, based in large part on his teaching evaluations. Unfortunately, these students were engaging with flipped instruction for the first time as seniors. If they had encountered it previously, they may have been more prepared for and satisfied with this mode of instruction. It is also possible that this was related to perceptions of a lack of course organization, since the course was being offered for the first time in flipped mode. Similarly, in a senior-level flipped control systems course, there was some initial student resistance to and frustration with inverted instruction. However, the students began to adjust after about four weeks. One student explained, "It took over half the quarter to finally get used to it. I recommend starting this learning style in a different class [30]." Another survey comment indicated that the new learning style "Should be implemented before senior year [30]." Although reasons were not provided, according to these authors, researchers are divided on using flipped formats in upper division courses [29]. Others have had similar experiences with seniors [31]. Interestingly, in his post-course interview, the instructor of our senior course felt that flipped instruction should *not* be used with upperclassmen not previously exposed to the pedagogy, in line with the goals of our freshman instructor. In the interview, the senior instructor reflected that his students had not taken full advantage of the structure of the flipped classroom, as only a minority used all of the available face-to-face class time to seek assistance or work on group projects. However, he did note an increase in computational ability based on successful models developed, compared to prior semesters. He also noted fewer "straightforward" student questions and felt that flipped instruction promoted deeper engagement and better career preparedness for his most highly motivated students, in line with his objective of increasing deep learning and higher order thinking. Thus, despite their resistance, some of our seniors appeared to experience academic gains in the course.

Since we noticed a lack of engagement with and resistance to the flipped classroom by our freshmen and seniors, we compared their classroom environment responses to those of the sophomores and juniors. The freshmen (n=250) rated every dimension lower in comparison to the sophomores and juniors (n=469). Five of the seven dimensions were significantly lower on the order of p<0.0005; four were associated with medium or large Cohen's d effect sizes. The seniors (n=74) rated five of the seven CUCEI dimensions lower than the sophomores and juniors did, with three being significantly lower on the order of p<0.0005. The associated three effect sizes were large. The seniors rated the satisfaction dimension at 2.75 on the five-point scale. This was lower than the average satisfaction rating of 3.49 by the sophomores and juniors (p<0.0005) and was associated with a large effect size of d=0.85.

Lessons Learned

One of the challenges that emerged for several of the instructors was serving as one consultant to many students during class, with some groups having to wait for assistance as the instructor circulated throughout the classroom. This has also been noted by other instructors. The signal processing instructor discussed previously assessed that a single faculty member could adequately coach about 30 students during class time [31]. Our facilities layout instructor concluded similarly during his pilot flipping and was able to recruit a teaching assistant who was knowledgeable in this subject area, so that two resources could assist the 70 students. In his second semester, this instructor was able to recruit a second TA, so that three resources were available, showing a nice evolution in meeting one of the larger challenges initially identified with flipping the course.

The online or in-class quizzes taken by our students after watching the videos emerged as helpful both for accountability purposes and for providing feedback on conceptual understanding and "muddiest" points. Zappe et al. recommended the use of online quizzes before class as an accountability check [7]. In his first semester of flipped instruction, our mechanical design instructor noted a lack of video preparation with some students and began administering quizzes at the semester midpoint. His observation was later corroborated by both the self-reported and web analytics data. Similarly, the mechanical engineering instructors at the University of North Dakota determined that there must be "gate checks," or assessments to ensure that students arrive to class prepared [23].

Our instructors found recording the videos to be time consuming and challenging, noting in some cases that "lecturing to an empty room" during the recording was more difficult than anticipated. We found that the inability to ask questions during an "online lecture" was a small disadvantage; this includes student as well as instructor-initiated questions. Another lesson learned was the realization that not all courses or topics may be well-suited to flipping. In a post-course interview, our facilities layout instructor identified specific topics that he felt were better suited than others, including one that involved the use of layout software. In general, he felt the better suited topics tended to be formulaic or mechanical. In their post-course interviews, three other instructors reiterated this conclusion about considering the topic or course before flipping it without specifically being asked the question.

CONCLUSIONS

Active learning in a flipped classroom enables students to apply and practice concepts and skills during class with the instructor present to provide coaching and support. At the same time, it promotes lifelong learning skills by requiring students to obtain pre-class exposure to course content through video lectures, thereby arriving to class prepared to work. Active learning leads to increased involvement in one's learning, enhanced understanding and outcomes, and a deeper learning experience, including the higher level skills in Bloom's taxonomy [8-9, 11]. Given these benefits, our school of engineering officially promoted the flipped classroom starting in the fall of 2013 across its multiple majors. Required freshmen through senior-level courses in introductory programming, statics/mechanics, mechanical design, bio-thermodynamics, facilities layout/material handling, and chemical engineering dynamics and modeling comprised an inaugural group of flipped engineering courses. To summarize our results, we return to our research questions.

RQ1: Does the flipped classroom promote student engagement during class, and does it positively impact the classroom environment?

Based on structured classroom observation and comparison against a national study, we were able to demonstrate highly active and interactive classrooms within our school-wide flipped classroom initiative. The TDOP elements of interest, including problem solving, small group work, individual active work, student discussion, and instructor coaching, were significantly higher in our classrooms compared to more traditional classrooms. For the statics/mechanics and facility layout courses, we were able to perform pre-flip classroom observation. With the statics course, which did not contain elements of active learning prior to flipped instruction, our structured observation revealed significant increases on the order of $p<0.01$ in the occurrence of small group work and student discussions. This course displayed an evolution over the academic year in the amount of interactivity and active learning during class; thus, instructional changes such as course flipping may require time for full implementation. With facility layout, there were also significant increases ($p<0.01$) in the percentages of problem solving, student discussions, and instructor circulation to answer questions when considered pre-flip to flip. Thus, in both courses, there was an opportunity for more student-centered, active learning during class, and our structured observation showed this opportunity to have been met by the flipped classroom. Based on these various comparisons, we conclude that flipped instruction drove student engagement and involvement in our engineering classrooms.

For two of the courses – statics/mechanics and facilities layout - we were able to administer a pre-flip environment survey. In statics, the flipped environment was rated as significantly better ($p<0.0005$) on four CUCEI dimensions compared to the pre-flip environment. These dimensions – student cohesiveness, individualization, involvement, and personalization - are key goals of the flipped classroom. The effect sizes were also large. In the facility layout course, there were also significant improvements in individualization and personalization ($p<0.0005$) as well as involvement ($p=0.002$). Based on nearly 800 classroom learning environment responses, the flipped classroom in our school was rated highest on the personalization dimension, scoring 3.88 on the five-point CUCEI scale. This dimension assesses interaction between the students and instructor; thus, students perceive student-faculty interaction as a strong aspect of the flipped classroom. Our school-wide CUCEI data compared favorably with other CUCEI studies of STEM classrooms in the literature. Thus, we conclude that flipped instruction had a positive impact on the environment in our engineering classrooms. Our freshmen and seniors, however, did not evaluate their flipped classroom environment as favorably as the sophomores and juniors did.

RQ2: Is the flipped classroom associated with increased student achievement and learning of content?

Exam, homework, and grade results in flipped vs. non-flipped courses at other universities have been mixed, as were ours. Two of our courses had statistically significant improvements in exams or homework and two showed statistically equivalent results. However, several of our instructors noticed improvements in higher-order thinking skills and content proficiency with flipped instruction. Our bio-thermodynamics instructor identified improvements in problem solving, including solution of more advanced problems, in his flipped class. Our SolidWorks instructor found that students in the flipped course were more sophisticated, proficient SolidWorks users; he attributed this to more practice time, which was possible in the flipped classroom. We found a correlation of approximately 0.40 between the number of videos accessed and the course grade for our sophomores, juniors, and seniors, suggesting some relationship between preparation in the flipped classroom and achievement. There was a very low correlation for the freshmen, which was not significantly different from zero. Based on two separate sources of data, the freshmen in large part did not make use of the videos as first-time instructional tools, as intended. Based on these same sources of data, the sophomores through seniors took greater responsibility in watching the videos before class. This suggests that freshmen may require additional coaching and monitoring in the flipped classroom, especially if they have not previously experienced this style of instruction. We found other examples in the literature in which preparation was an issue of concern in freshmen flipped classrooms. In addition, we encountered resistance by our seniors to flipped instruction and likewise uncovered examples in the literature of resistance by seniors.

RQ3: What strengths, benefits, and drawbacks do students perceive with the flipped classroom?

The flipped classroom evaluation survey showed an approximate three-way split in student preferences for the flipped classroom, with 27% indicating a preference, 36% indicating a non-preference, and 36% being unsure. The students nonetheless saw value in this method of instruction, as 57% of respondents preferred using class time for problem solving or active learning with the instructor present versus listening to a lecture. In an open-ended response, the most frequently stated benefits of the flipped classroom included flexibility and convenience-related benefits (44% of respondents), enhanced learning or learning process (31%), and alternative use of class time (25%). There were a small percentage of respondents (10%) who identified preparation, engagement, and professional behaviors as a benefit.

We believe that flipped instruction is an effective learning approach, despite some challenges we encountered. Like all pedagogies that challenge the status quo, there are issues, aspects, and challenges that must be considered and understood. Flipped instruction promotes more active learning and responsibility for life-long learning, student engagement, interaction in the classroom, collaboration, individualization and flexibility, preparation, and more real-world engineering experiences in the classroom. Over the past academic year, the members of our faculty learning community have considered, and in some cases re-thought, their approaches with this pedagogy and have reflected on other lessons learned. In the process, we discovered the advantage to introducing the flipped method of instruction early in the undergraduate career. Although our freshmen did not engage with the flipped classroom as intended in terms of the video usage, introducing this method of instruction to them as freshmen likely better prepared them to engage with it in their sophomore years and beyond. Thus, one of the instructors' main takeaways was the need to educate students upfront about the expectations and goals of the flipped classroom, which we aptly did by developing a student-produced video on flipping. Going forward, this video will be distributed at the start of the term to orient students to their new learning environment and prepare them for the expectations of the flipped classroom.

All but one of the instructors continued to use the flipped instructional style in the course. Our senior-level instructor decided not to flip the course the following term but would like to return to this teaching style in the future. We continue to promote and formally support the flipped style in our school of engineering, and additional instructors continue to implement the approach to drive active learning and in-class engagement with their students.

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