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Understanding the Benefits of the Flipped Classroom in the Context of Sustainable Engineering

Jayne Marks, University of Pittsburgh
Kevin J. Ketchman, University of Pittsburgh
Dr. David R Riley II, Pennsylvania State University, University Park

Dr. David Riley is a faculty member in the Penn State Department of Architectural Engineering. His fields of expertise include education for sustainability, sustainable building methods, renewable energy deployment, and sustainable housing design. Dr Riley directed Penn State's Center for Sustainability (now Sustainability Institute) from 2005 to 2013. He currently serves as the Senior Resident Scholar and Reinvention Fund Program Manager for the Institute. Dr. Riley also leads multiple DOE funded energy centers, including the Northern Mid-Atlantic Solar Education and Resource Center, and the Grid-Smart Application and Resource Center. In 2009 he initiated the launch of the National Energy Leadership Corps (NELC), a hands-on program that challenges college students to engage residents in their communities in meaningful home energy and sustainability planning and actions. He is now working with collaborators at numerous institutions to advance the and replicate the NELC in sustainable and high-impact applications.

Dr. Lisa Riley Brown, Penn State University
Dr. Melissa M. Bilec, University of Pittsburgh

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Abstract

Engineering is a field marked by critical thinking, problem solving, and application of vast amounts of scientific and technical knowledge. College-level engineering courses often focus on learning scientific material and are challenged to provide an opportunity for students to apply this material or develop the above skills necessary for success in the field. Because of this disconnect, a teaching method known as the flipped classroom is gaining consideration and implementation in engineering classes as well as in classrooms of many levels and disciplines. In a flipped classroom, live class lectures are moved out of classroom and replaced with on-line videos, and active, project-based learning activities are done in their place. At the University of Pittsburgh and Pennsylvania State University two sustainable engineering courses focused on residential energy efficiency were flipped, and the impact this method had on the students was investigated.

For this study, data was collected using pre- and post-confidence tests, a final course reflection survey, and the College and University Classroom Environment Inventory (CUCEI). This data was then analyzed and used to develop conclusions on the students' perception of the flipped classroom teaching method and the course. Students in both courses frequently expressed that they learned various personal skills such as leadership, listening, and communication, which were consistent with class objectives. The tones of the student responses were positive, and on the CUCEI, the students scored the class environment above average. The highest scoring section of the CUCEI, 4 out of 5, was *Personalization*, which includes professor availability and highlights how a flipped classroom provides students with more opportunity to interact and connect personally with the teacher. As expected, the *Involvement* section, pertaining to student participation in in-class activities and class discussions, also scored high at 3.94 out of 5. Student comments were generally positive such as, "*It was great that there was always time in class to ask about the module and topics I didn't understand*," or, "*I thought it created a more comfortable learning environment in class and allowed students to learn in their own way at home*." Our findings suggest that the flipped classroom was a successful teaching method for these sustainable engineering courses.

1. Introduction

Today, many engineering courses are taught using the traditional classroom lecture method. Students attend lecture, listen to their instructors deliver large amounts of information, and then attempt to apply this information outside of the class by doing homework. However, it has been noted that this form of teaching has shortcomings that could be impacting students' education and their ability to retain, analyze, and apply knowledge [1]. Some of the noted limitations include the small amount of teacher-student interaction, the rigid pace of the lecture, and that lectures only take advantage of one information delivery method [2, 3]. These disadvantages will not apply to every form of lecture, and some alternative interactive lecturing methods have been developed. In addition, the traditional lecture method can be useful for delivering large amounts of information in the small amount of class time provided. However, in some curriculum, specifically engineering, a strong emphasis on active learning can be beneficial to students.

To address this disconnect between delivery and student-learning, the flipped classroom teaching method has been gaining popularity. Additionally, reasonable technology is available to facilitate this delivery method. The flipped classroom often takes lectures normally given during class time and moves them outside of the classroom in the form of recorded videos or voice-over PowerPoint slides. The students watch the lecture on their own time and are able to pause, rewind, take notes, and re-watch the lectures as many times as is necessary to understand the material. These videos are usually accompanied by some kind of quiz to ensure students are watching the videos. During class, teachers take advantage of the time by employing active learning exercises that apply the knowledge learned from the lecture in a hopefully deeper way. This delivery method is intended to promote student-teacher interaction, problem solving and decision making skills, teamwork, leadership, and responsibility because the in-class activities tend to be teamwork based and critical thinking oriented [4]. Flipping can allow students to take more responsibility for their education and the instructor to act as a guide, answering questions and helping students as questions arise. However, it has been noted that this method would not work well for larger class sizes, that there is a possibility of students not watching the videos, and that it is still not known if students can learn and connect with their instructor through video lectures in the same way as with traditional lectures [5, 6].

The problems associated with traditional teaching methods are especially important in the study of engineering. Engineering is a field that relies heavily on applying knowledge and using critical thinking to solve problems. While many undergraduate engineering courses are taught through lecture, applying the flipped classroom teaching method can give students an opportunity to improve application and critical thinking skills through in-class discussions and activities. The Pennsylvania State University (Penn State) and University of Pittsburgh (UPitt) flipped two undergraduate engineering courses and studied the effects on student learning as well as student perception of classroom environment in the seven psychosocial dimensions: personalization, involvement, student cohesiveness, satisfaction, task orientation, innovation, and individualization.

2. Class Information

The University of Pittsburgh is a public university with 16,719 full time undergraduates and 10,297 graduate students. The flipped class contained 33 students of mixed majors and years in school, but was predominately civil and environmental students. The class was CEE 1218/2218-Design for the Environment, an experiential learning course in which students are challenged to apply concepts of sustainability through tangible and appropriate projects carried out with a partnering community/project. The Pennsylvania State University is a public university with 36,749 full time undergraduates and 6,418 graduate students. The flipped class was of similar design and make-up, containing 12 students of mixed majors and years in school.

Both classes were pilot programs for the National Energy Leadership Corps (NELC). The NELC is a joint program under development at Penn State and UPitt and is designed to teach students about home energy efficiency and sustainability and empower them to conduct home energy assessments in their community. The design of the program reflects the need for alternative models to personally engage homeowners in a holistic approach to home energy and sustainability concepts and also respond to the limitations of traditional professional home energy audit processes that are focused on motivating homeowners to invest in home energy improvements [7] The multifaceted program begins in the classroom where students are first taught about energy assessments and the home as a system in a flipped-classroom education model, and then provided hands-on training in the performance of in-home energy assessments and culminates with a student-authored personalized educational report to homeowners on their home's energy profile and ways to improve efficiency, safety, and health.

The semester-long course is designed to teach students technical information in the major concentrations of home energy assessments, health and safety, building materials, air infiltration, heating and cooling, and energy management and security. Unique to the course are modules dedicated to developing trust and being respectful of the variable world views they may encounter during home energy assessments. Near the end of the course, students complete two home energy assessments. In teams of three or four, students ideally perform their first "practice" assessment in the friendly environment of a faculty member or another accessible location with support from a teaching assistant. The second assessment, also the student's final project, takes place in a home outside of the university community identified through collaboration with neighborhood organizations or other trusted community-based networks. Each team was assigned a home in the Pittsburgh, PA or State College, PA area and performed the assessment with minimal support by the teaching assistant. Students delivered an energy assessment report to the homeowners, providing the homeowner with a general overview of their current energy profile, health and safety topics, and energy improvement recommendations.

The report delivered to the homeowner is personalized to their worldview and cognitive style, determined through a survey performed at the time of the assessment, and the home's current energy profile, obtained through the assessment and utility bills collected. The report is meant to inform the homeowner of ways to improve their energy use through retrofits or upgrades and educate them on how these energy efficiency measures (EEM) will improve their energy use as well as the comfort and safety of the home.

3. Methods

3.1 Module Tests

Throughout both courses, lectures were moved out of the classroom in the form of video presentations. Each of the ten modules consisted of anticipatory questions, a pre- and post-module confidence test, videos and learning check quizzes. Videos were limited to three to eight minutes. The results of the pre-and post-confidence questions are intended to be used as key indicators of student gains. These questions are presented prior to the first video in a module and also at the end of the module as follows: "How confident are you in your: *Ability to (insert relevant content here for example describe how we use energy in our homes?)* 1: Not a Clue; 2: Not Confident; 3: Somewhat Confident; 4: Confident; 5: Very Confident." A screenshot of a module can be seen below in Figure 1.

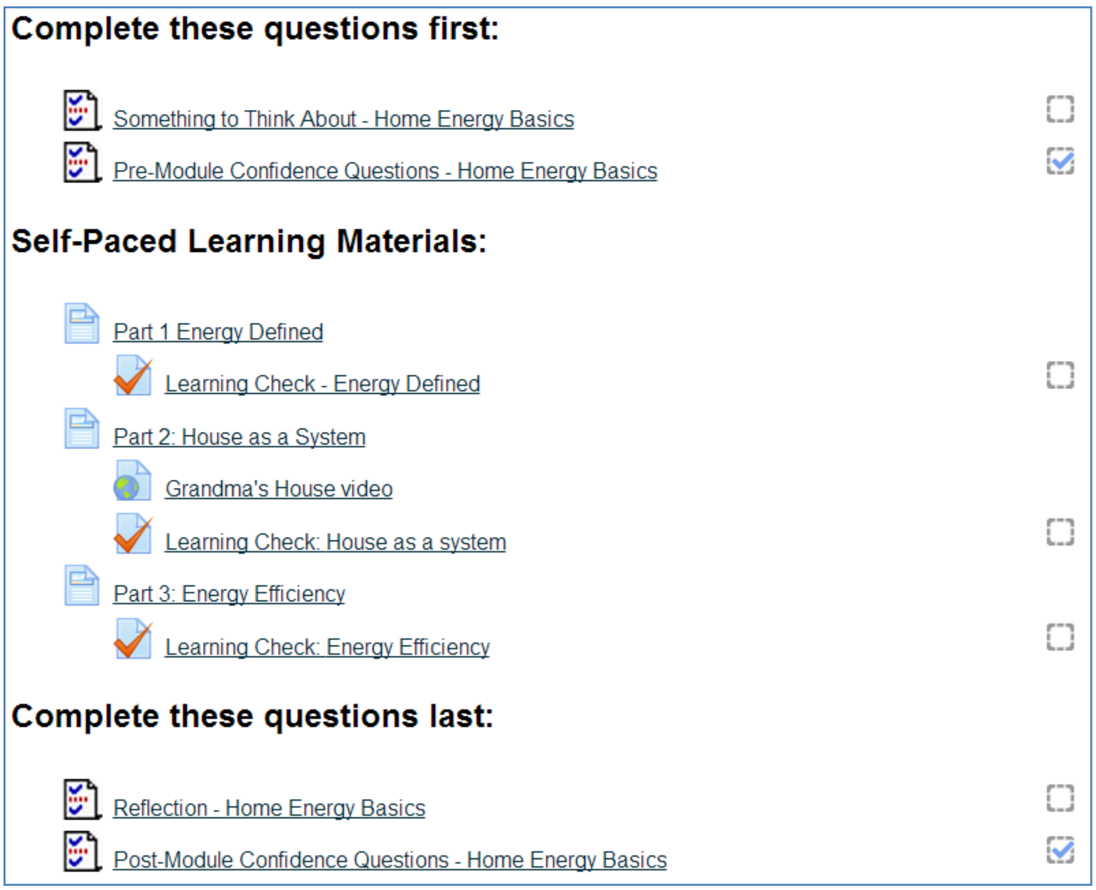

Figure 1. A screenshot of module 3 serves as an example of the typical module set-up

3.2 Course Reflection

In addition to the module pre- and post- tests, a survey was given to students at the end of the class. The survey consisted of eight questions relating to the experiences the student had in the class and what their opinion on these issues was. Questions used in the survey can be seen in Figure 2.

Thirty students (100% response rate) completed the survey in the UPitt class; twelve (100% response rate) completed the survey in the Penn State class. All students were assigned a number from one to 30 or a letter from A to L in order to preserve anonymity. The answers from students in each section were then codified in order to find trends in student opinions and ideas about the class. Codes in qualitative data analysis are tags, names, or labels and coding is the process of putting tags, names, or labels against pieces of data. In the Miles and Huberman [8] approach that was loosely used for this project, there are two main types of codes—descriptive codes and inferential (or pattern) codes. Descriptive codes are early labels, requiring little or no inference beyond the piece of data itself, while pattern codes require some degree of inference beyond the data and pull the material into smaller, less abstract, meaningful units. This method of first descriptively codifying followed by creating pattern codes was used to identify themes in student responses which could then be recorded into a numerical representation of the frequency of the codes.

1) Please describe three ways your understanding of the challenges of leadership and home energy efficiency evolved or changed through your experience in this course.

2) Please describe how your experience with a homeowner, in their home, made an impression on your understanding of the skills and traits needed for leadership in sustainability.

3) An early piece of advice you received in this course was that when sharing sustainability concepts and ideas with new audiences, there is a need to meet people where they are. "What does this advice mean to you now and how has your understanding of this advice evolved during this course?"

4) Based on your experience in this course, how would you describe the key aspects of leadership in sustainability? How did the home energy assessment project expose you to some of these aspects?

5) Reflect upon your experience with the development of an educational script for the MorningStar, the design and construction of an educational garden, and your efforts to conduct an educational energy assessment. How have these experiences informed your awareness of your own strengths and weaknesses as a leader? How will you apply this awareness to your next opportunity to work on a team project?

6) Please describe your overall expectations for this course prior to the semester, and how these expectations were or were not met by the course.

7) How would you suggest future versions of this course change in ways that would strengthen students' understanding of leadership in sustainability, and also development of leadership skills?

8) Please share any additional feedback on this semester or ideas for future offerings of this course.

Figure 2. Questions of the final course reflection given to students at the end of the semester

3.3 College and University Classroom Environment Inventory

Along with the above two methods, a third was used only in the University of Pittsburgh class. The College and University Classroom Environment Inventory (CUCEI) survey was given to 22 students at the end of the semester, and is used to assess students' perceptions of the following seven psychosocial dimensions of classroom environment; student cohesiveness, innovation, individualization, involvement, personalization, satisfaction, and task orientation. This test has been used to assess classroom environment as opposed to the direct observation approach due to the benefits that come from a student's perspective and the possibility that an observer could miss or consider data unimportant. It was developed specifically to assess the class environment in smaller, university level classes and therefore has been used previously in higher education as a valuable tool [9, 10]. The test was administered and scored by the Engineering Education Research Center at UPitt.

This survey is done by giving students a list of 49 statements and asking them to rate Strongly Agree (1), Agree (2), Neutral (3), Disagree (4), or Strongly Disagree (5). This scale is reversed for half of the questions to ensure full participation in the reflection survey and that students are not brushing aside reading the question before answering. There are seven statements for each of the seven above psychosocial dimensions, and statements include those such as "The instructor considers students' feelings," and "Each student knows the other members of the class by their first names." The score for the class is then calculated and given as a number out of five with five being the best [11]. Additional explanations of the seven psychosocial dimensions of classroom environment are illustrated in Table 1.

Table 1. Explanations for the seven psychosocial dimensions of classroom environment

Student Cohesiveness:	Students know, help, and are friendly to one another
Individualization:	Students can make decisions; students treated differentially/individually
Innovation:	Instructor plans new/unusual class activities, assignments & teaching techniques
Involvement:	Students participate actively/attentively in class discussions & activities
Personalization:	Opportunities for students to interact with instructor; concern for students' welfare
Satisfaction:	Enjoyment of classes
Task Orientation:	Class activities are clear & well organized

4. Results

The results of the module tests, final course reflection, and the CUCEI are summarized. After analyzing the results from the UPitt pre- and post-confidence tests, there was an increase in confidence. The questions were answered on a scale from 1 to 5, 5 being 'Very Confident.' The mean answer for all of the pre-module tests was 2.75/5 with the post-module tests' mean of 4.27/5: an increase of +1.53. The frequency of the responses 'No Clue', 'Not Confident', 'Somewhat Confident', 'Confident', and 'Very Confident' also changed. There was an increase in 'Confident' and 'Very Confident' answer frequency accompanied by an overall decrease in 'No Clue' 'Not Confident' and 'Somewhat Confident' answer frequency from the initial test before using the learning module to the post-test afterwards, see Figure 3A..

Similar results were seen with the Penn State class. The mean answer for all of the pre-module tests was 2.66/5 with the post-module tests' mean of 3.98/5: an increase of +1.32. Additionally, there was an increase in 'Confident' and 'Very Confident' answer frequency accompanied by an overall decrease in 'No Clue' 'Not Confident' and 'Somewhat Confident' answer frequency, see Figure 3B.

After analyzing the answers to the final course reflection survey, some trends were identified. Though the questions did not directly ask about the flipped classroom teaching method, advantages associated with it were frequently mentioned in the student responses. More than half of the UPitt students (16/30) stated that they frequently were able to put their class knowledge to use during activities of the class and that they learned skills that are useful for their future or their future careers. Some of the skills mentioned include adaptability (15/30), leadership (18/30), and communication (18/30). Five students made a point to say they liked the flipped classroom structure, though the questions made no mention of it, and more than half of the students had something positive to say about the class. For example, Student 8 said, "*I really enjoyed the flipped classroom style of learning and benefited from it. I thought it created a more comfortable learning environment in class and allowed students to learn in their own way at home*." Similarly, Student 2 wrote "*…during this semester I found team work is really more interesting than working individually*."

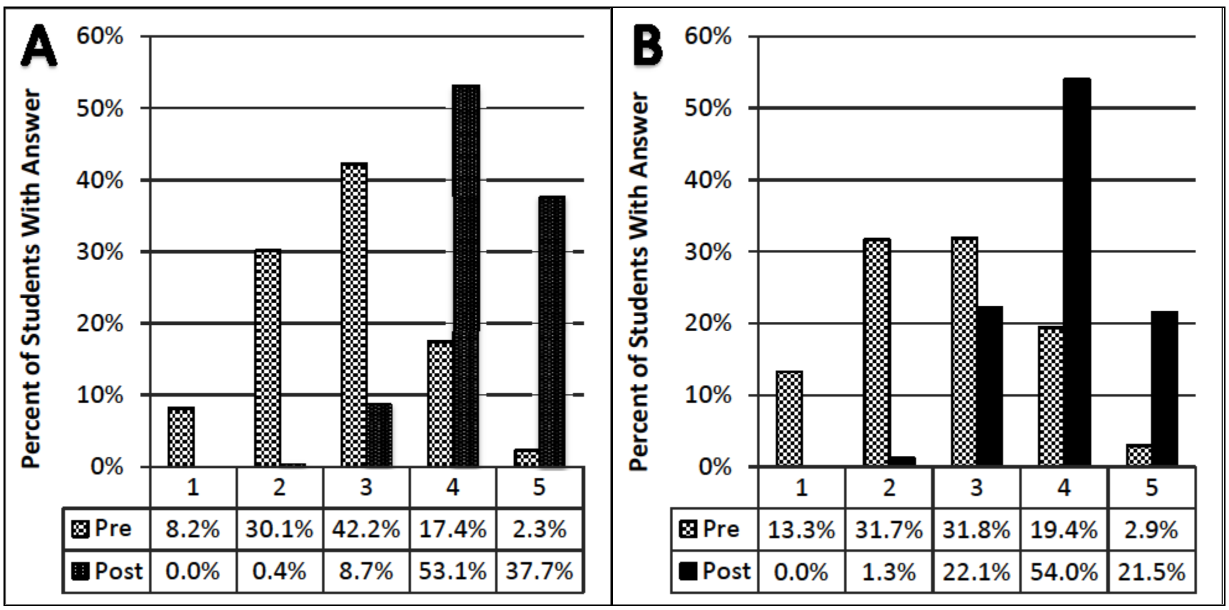

Figure 3. A) Average frequency of answer for the pre-tests and post-tests for the participant university. Class size: 30. B) Average frequency of answer for the pre-tests and post-tests for the host university. Class size: 12. 1 = No Clue, 2 = Not Confident, 3 = Somewhat Confident, 4 = Confident, 5 = Very Confident.

The Penn State course had similar outcomes. More than half of the students had extremely positive view of the class such as this opinion shared by Student C: "*This unconventional way of teaching with time spent at the morning star [sic] classroom discussions and hands on work proved to make the class great!*" A majority of students shared that they learned communication skills (9/12) and leadership skills (11/12), and many students wrote that they learned to customize their arguments to their audience (10/12), learned to understand different points of view (10/12), and learned something new about themselves (9/12). Like the UPitt class, students stated that they used knowledge from class during their active learning activities and that they gained skills and knowledge that will be useful in the future. Along with learning from the active learning activities, over half wrote that they enjoyed doing the hands on activities and specifically the Home Energy Assessment project done with the NELC, which allowed them to interact with homeowners and apply their knowledge of energy use in homes. This can be seen in these quotes by Student F and Student J:

"The modules really helped me to increase my knowledge about systems and general topics of sustainability…. I like that we had the possibility to do things in reality such as the Home Energy Assessment."

"… [We] apply this knowledge in the field so that the knowledge is not lost and becomes a skill."

Six students in the UPitt class and five in the Penn State class mentioned how the video modules helped their learning. One student stated "*I enjoyed the online lectures not only because they were short but also I remembered the material easier than if someone were to lecture all of the material straight through (the short videos and questions in between stimulated my thoughts easily).*" Another wrote, "*I think the content of the class was made very easy to understand through the modules*."

Very few students in either class had anything negative to say about the course. A few suggestions were: using more physical papers, having a place online to discuss the lecture with classmates, better utilizing class time, having a more structured schedule, teaching to a smaller class size, and wanting to cover details that are more technical. These challenges were brought up by no more than four students and are all common challenges associated with the flipped classroom teaching method.

The final method of data collection was only performed at the University of Pittsburgh. The College and University Classroom Environment Inventory (CUCEI) survey was given to students at the end of class. The results of this test are shown below in Table 2, with a score of three or above in each of the seven categories.

Dimension	Average Score
Student Cohesiveness	3.20
Individualization	3.01
Innovation	3.22
Involvement	3.94
Personalization	3.99
Satisfaction	3.79
Task Orientation	3.85

Table 2. Results of the UPitt course's CUCEI. Sample size = 22.

5. Discussion

Students in both courses frequently expressed that they learned various personal skills such as leadership, listening, and communication, which were consistent with the class objectives and advantages noted in the literature. The tones of the student responses were generally positive, and on the CUCEI, the students scored the class environment above average. This suggests that students were open to classes being taught in this way, and that there are benefits associated with the flipped classroom that are not available through traditional lecturing methods.

From the above data, it can be seen that the class was successful in teaching the students the material. This is evident from the large increase in confidence from the pre-module tests to the post- module tests. It can be concluded that the modules are a feasible way to present the information and that students are able to learn from them. However, a control group would be needed to see if the students' confidence increased on a scale that is comparable to traditional teaching methods.

Along with the affirmation of learning found by the pre- and post- tests, the themes found in the final course reflection answers show an overall positive view of the class, with little to no complaints related to the flipped structure. It can be seen that many personal and professional skills such as leadership, communication, adaptability, understanding of differing views, and personal strengths and weaknesses were emphasized. Within the final course reflection survey, many students noted learning the importance of these skills. This accomplishes the three course objectives seen below:

1. Formulate and design solutions that take into account the effects of worldview on the motivation and behavior of individuals.
2. Communicate project results and solutions to community-based audiences in both written and oral form.
3. Articulate personal awareness and participate in self-assessment and reflective activities that are focused upon the awareness and cultivation of leadership skills.

Gaining these professional skills is also an outcome that is consistent with advantages found in the literature on flipped classrooms. Researchers Lage, Platt, and Treglia noted that students taught using the flipped classroom method developed communication skills and improved their potential job skills [6]. They also noted an increase in student responsibility and increased opportunities for critical analysis. This can be seen in the classroom of the UPitt course through this quote by one student: "*I like the form of this kind of class [sic] we learn by ourselves at home and discuss what we learned in class*." Similarly, a paper by He, Swenson & Lents noted that using videos as opposed to lectures allowed students to pause, take notes, look at the textbook, and rewind to better understand the material and move at a personal pace [12]. A student in the Penn State course conveyed approval of the video lectures in a quote taken from the CUCEI survey:

"The modules in general were great. During the videos, I continuously stopped and wrote down all additional information and when I couldn't remember something I just looked up in my

notes. I also liked to [sic] online tests after to check the knowledge to make sure I understood. It was great that there was always enough time in class to ask about the modules and topics I didn't understand."

Similar quotes can be seen throughout the surveys pointing to a positive student perception of the course. This was confirmed with the results of the CUCEI. In all seven categories, the students scored the course higher than average (2.5/5) with the highest score being 3.99/5 in the category of 'Personalization'. Personalization is defined as the availability of opportunities for students to interact with the instructor and whether or not the instructor appeared concerned with the success of the students. This result is consistent with the literature review advantage that flipping the classroom will provide students with more teacher interaction and allow teachers to connect personally with their students. The second highest scored category on the CUCEI was 'Involvement' with a 3.94/5. The involvement category is meant to measure student's participation in in-class activities and class discussions. By moving the lectures out of the classroom, not only does it take a passive student centered class and turn it into an active learning environment, it also frees up time for more activities and discussions [3]. The results of the CUCEI agree with this.

In addition, because the students scored the CUCEI higher than average, it can be inferred that this above average class environment would have a positive effect on the student's learning. Research has shown strong correlations between classroom environment and student outcomes, such as the 1972 study by Walberg, which reinforced Bloom's theory that measurements on the same characteristics can be predicted when considerations of environment are included [13, 14]. Fraser and Treagust [11] found that classes with better environments, those containing cohesiveness, organization, goal direction and satisfaction, also saw greater outcomes on a variety of measures. Because of the high scores given by the students of the UPitt class, it is evident that the flipped classroom environment is one that promotes learning and achievement.

Through this study, it has been found that the students of the two flipped engineering courses felt they learned valuable skills for the future such as communication, leadership, and teamwork. They also noted that the time used in class for group discussion was helpful to them, and that through active learning activities, they were able to put the knowledge they learned in class to use as a skill. There was a general increase in confidence across both classes after completing the learning modules, which many stated were helpful. There was also evidence of a greater connection between the teacher and the students through the high scores in the 'Personalization' and 'Involvement' categories of the CUCEI. These results point to a successful course and a positive perception of the flipped classroom by students suggesting this method could be used in engineering classrooms in the future.

6. Future Work

Recently, studies have narrowed the attention on implementation of a flipped classroom in differing fields, such as medicine [15], engineering [3, 4, 16], and numerous other STEM courses [6, 12, 17], focusing on student outcomes for a particular semester. Information on student retention of learned materials is needed to examine the efficacy of the flipped classroom teaching model as opposed to the traditional method. The flipped courses at Penn State and UPitt are ongoing, presenting an opportunity to gather needed data on student outcomes as well as building a database of students who have taken the course and are able to participate in a follow up study to determine retained knowledge of the taught material. A goal of the NELC is to facilitate student-led home energy assessments across the U.S. through the shared use of the online modules and facilitate the ability of college and university instructors to adopt this activity in their courses. Continuing research on the value and impact of the flipped classroom setting and the design of in-class activities to support and compliment the online modules will be performed in pursuit of this goal.

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