Flipping a Classroom: A Continual Process of Refinement

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1. INTRODUCTION

To meet the educational needs of twenty-first century students and twenty-first century society, innovative curriculum and instructional practices are being developed and implemented to expand and transfer knowledge not only into the classroom, but also out of the classroom to professional settings. The SMART LIGHTING Engineering Research Center (ERC) educational program's goal is to educate a workforce need to expand the domain of Smart Lighting. To do so, the ERC is investigating alternative approaches to instruction that will build on the constructionist/ constructivist approach to STEM education. As part of these efforts, the instructional approach known as *flipped classrooms* has been piloted and implemented since 2010. Using this approach class content is provided using online video lectures and class time is designated for practice and reinforcement of concepts using active learning techniques. Flipping a classroom is not a simple approach that is perfected in its first implementation, but is rather a process that includes thoughtful monitoring and assessment to provide students with the self-direction and regulation necessary for this approach. Although this approach is more and more common, students still remain most familiar with more traditional methods of teaching, particularly in STEM higher education settings. Although many students have prior experience with video lectures, their comfort levels are generally not high when it is the sole method of obtaining information (i.e., no formal lecture). The focus of this effort is to provide students with an environment that eases the transition and anxiety from traditional methods to more student-centered learning by using guided inquiry and scaffolding techniques.

The purpose of this paper is to present formative information related to the implementation of a flipped classroom approach in an Electronics Instrumentation class beginning in 2010 through 2013. Student and faculty perceptions of the use of online video lectures and the in-class active experiential learning (i.e., how both methods were used, their impact on student affect and cognition, as well as facilitators and barriers) and documentation of the process of continual development used to refine the implementation of the flipped classroom approach, specifically in Spring and Fall of 2013 are presented.

2. Theoretical Background

In today's society, the STEM workforce is required to possess skills in areas of innovation, creativity, problem-solving, multi-tasking, and collaboration[1,2]. To cultivate and develop these skills, much focus has been placed on higher education in STEM domains and the instruction that is provided to students. The goal to provide instruction that will improve learning and elicit a highly qualified workforce with critical thinking skills is not new. Constructivist-based learning, inquiry learning, and self-regulated learning are all methods of learning grounded in deep thinking, guided teaching, and active participation that have been shown to be effective in helping students obtain and retain skills and new concepts, overtime showing greater proficiency and expertise in content[3-12]. Over time, various approaches to implementing these theories of learning have been revised and reinstated to better serve the needs of the students and society. For example, using these approaches alongside multimedia to supplement learning and provide blended learning via simulations, tutorials, videoconferencing or solely online learning are all more current approaches that dovetail with constructivist and constructionist-based approaches to

learning and practices[3,6-13]. The implementation of what are now called "flipped classrooms", piloted by two STEM high school teachers, Bergmann and Sams, is a more recent approach to teaching that is supported by these learning theories. The flipped classrooms approach is an innovative technique that enhances content-based learning, while offering more time for individualized practice and skills acquisition[14].

In higher education settings, various characteristics and strategies of instruction are already in use that are similar to the flipped classroom including using the internet for instruction to provide flexible learning accommodations for students[15]. Flipped classrooms, as they are coined, use technology to provide students with conceptual information outside the formal education setting. Generally, this occurs before practice and in a sense becomes the "homework" required of students. The class instructional time is now spent on practice, reinforcement, and mastery of the conceptual information through guided, active experimentation[15-18]. Moving experimentation and rehearsal inside the classroom allows instructors to take on a facilitator role to provide individualized instruction to students and monitor collaborative activities[16, 19-21].

The flipped classroom approach strives to eliminate time constraints and lack of student understanding between lecture and practice by using technology to review basic content knowledge outside the classroom and thus, to engage in active learning inside the classroom[22]. This flipping of the classroom structure allows the instructors and the students time during class to focus on activities that cultivate creativity, critical thinking, discovery-based problem solving, and skills in communication[22-24].

This paper presents the process of developing and implementing instruction using a flipped classroom approach in an Electronics Instrumentation class. Student and faculty perceptions of the approach from Spring 2013 and Fall 2013 are provided.

3. Methods

Students enrolled in the Electronics Instrumentation class represented primarily undergraduate mechanical or dual aeronautical and mechanical engineering students. The flipped classroom approach supported multiple learning styles and preference for instruction. The student demographics reflected traditional enrollment patterns for engineering programs; in Spring 2013 specifically, over three-quarters of students were male (86%), three-quarters (76%) of the students were white and 24% represented ethnic minorities. A majority (82%) of the students were in their third or fourth year of their undergraduate studies. Nearly all of the students (93%) were enrolled in mechanical engineering (59%) or dual aeronautical and mechanical engineering (24%) programs. The course was recently changed to permit second year students to take it, but the position of the course in the mechanical engineering program was not changed. Eleven percent of students' reported a native language other than English. A total of 68 students participated in Spring 2013.

Using the flipped classroom approach, video lectures were available to students on *YouTube* that students viewed on their own time through their own self-direction. Nearly all video lectures were approximately 5 minutes in length and available for students to refer to at all times. The in-class time was spent on assignments developed for groups of two and four. Students assigned themselves responsibilities and tasks for each activity and the instructor and teaching assistants

monitored the students' progress and assessed their performance using a task checklist for each activity. Students documented their perceptions of their learning outcomes and the use of video lectures at the beginning and end of the course. Teaching Assistants (TAs) and the instructor were interviewed at the end of the course and observations were conducted by an external party throughout the course.

Results

4.a. The Process of Flipping a Classroom

In 2009-2010, a series of online video lectures and supporting materials were created that covered important theories, concepts, and demonstrations related to electronic instrumentation in an effort to support flipped learning in an Electronic Instrumentation Course at RPI. The videos and materials were placed on RPI's online learning management system and the course website for the students to view at their convenience, while providing a method for the instructor to replace the traditional classroom lecture with additional experiential time. Each covered key areas of theoretical and content knowledge. A constructivist approach to problem-solving was implemented. The TAs and instructor provided guidance and assistance as needed; however, students were still required to complete the work themselves.

In 2010-2011, the flipped classroom again was piloted in Electronic Instrumentation courses; the online videos were refined and expanded and used outside of class time for direct instruction. Self-directed experiential group work was implemented during the scheduled class time. During this phase, group work was conducted in partner-based assignments (i.e., experiments, n=8) and team-based assignments (projects, n=4). Partnerships and teams were self-selected by the students; there were approximately 25-30 partnerships and 12-15 teams per class section. Experiments were used to teach specific skills, while projects allowed for more creativity in design (e.g., "…*there was a design element* [to the projects]"; and *"There was more brainstorming and trial and error* [with the projects and] *I noticed that* [they] *were not as clearly defined in terms of steps so it was up to the group to determine the steps."*). Experiments were grounded in a guided inquiry instructional technique; the projects were based on more of a constructivist approach.

Table 1
Flipped Classroom Implementation

Year	Implementation Phase	Flipped Classroom Aspect	Formative Feedback			
			Pre-Survey	Post-Survey	Interviews**	Observations
2009-10*	Develop and Pilot	• Online videos created	141	141	7	3
2010-11*	Pilot	• Online videos used as direct instruction outside of class • Self-directed group work	183	183	3	10
2011-12	Integration and Refinement	• Supplementary materials created to support students' learning • Refinement of group work	105	103	8	29

		• Formative assessment techniques implemented				
2012-13	Refinement	• Additional learning opportunities developed • User-friendly features added to online videos • Refinement of formative assessment	127	138	21	37

Pre and Post-survey data for 2009-10 and 2010-11 represented matched data.
**Interview counts include both student and TA interviews.

Student evaluations of the videos and the subsequent activities (in Fall 2010, Spring 2011, and Fall 2011) provided formative feedback on perceptions and usage of the videos, allowing for improvements and further developments in the videos. As a result, supplementary video materials were developed and all videos were placed on *YouTube* in 2011-2012, creating greater accessibility and usability for students, but decreasing formative technique assessment for the instructor and TAs.

In 2011-12, modifications also were made on the assessment process of students' group work to support and document knowledge retention and students' level of self-direction. These included a troubleshooting document for students to reference, videos on higher level thinking, a rubric-oriented check-off process for students and the instructor or TAs to discuss after students completed each task to ensure understanding and expectations were met. Based on student feedback, the instructor also increased the number of TAs from two to three per class section allowing students to ask more questions if desired.

In Spring 2013, further refinement of the flipped classroom enhanced student learning opportunities. A questioning technique was implemented based on the "Think, Pair, Share" teaching strategy where the instructor posed a question based on course material for students to think about individually; they then worked in groups of four to answer. A brief three to five minute discussion also was implemented midway through the class to ensure student understanding. In addition, search tags were added to the videos' *YouTube* site and the course website was restructured to provide a more user-friendly format for students.

In Fall 2013, changes were made in effort to enhance and extend student learning at a higher level of cognition and transfer. Effective teaching practices and formative assessment procedures have been implemented for both students and teaching assistants to enhance the quality and depth of student understanding through both classroom activities and student summative performance tasks (i.e., lab reports) to facilitate learning for all students.

4.b Experiential Group Learning—Enhancing Communication and Problem-Solving Skills

In conjunction with implementing a flipped classroom, the instructor cultivated a hands-on collaborative learning environment for the students through student-directed group work. In an attempt to guarantee a collaborative learning environment, the instructor used lab assignments (experiments and projects) which required working in dyads and groups of four, ensuring that students engaged in some form of student-centered, active learning within the flipped classroom.

Evidence of the use of this approach was supported by students' responses to learning questionnaires and further confirmed by classroom observations.

The majority of activities related to learning were directed by the group (two or four students depending on the activity) as a collaborative effort, providing evidence of a constructivist approach to learning in the flipped classroom.

Table 2
Primary Decision-Maker by Activity*

Activities	Decision-maker					
	Instructor	TAs	Team Leader	A member of my team	My team as a group	Decided myself
Setting the content of the lab.	85	5	3	0	7	0
Establishing short-term goals.	18	3	3	7	61	8
Dividing the tasks.	0	0	3	5	88	4
Documenting progress.	0	5	0	15	67	13
Deciding to move on to the next task.	0	0	0	10	66	24
Completing the lab write-ups.	0	0	0	0	96	4

*Numbers represent the percent of students who selected the decision-maker for each activity on the post-survey N=68.

Student data indicated that the majority of decisions pertaining to group work were made as a collaborative group. Only the overall content of the lab assignment, including what the final product was and what was to be handed in to the instructor, was decided by the instructor. As a group, the students assumed all decisions for activities (e.g., establishing goals for their assignments, figuring out how to divide the tasks, documenting the progress they've made, and writing up the results). Nearly all students (96%) reported deciding how to complete the lab write-up as a group, indicating that even the work predominantly completed outside of class was not left for one person to solely address or to determine the best way to complete it.

Students indicated coordination and communication were skills needed for successful completion of tasks. In addition, successful group work also required higher level critical thinking skills and the ability to generalize concepts and apply them to a "big" idea. As the student partnership and group work was implemented, students had to work to collaborate with one another and understand each other to complete the partner work (i.e, experiments) and group work (i.e., projects). When queried on their experience in participating in both group and partner work, many students reported they: 1) developed or improved communication skills, 2) had to play to people's strengths, and 3) needed to learn to coordinate work in attempts to maximize efficiency (e.g., *"Coordinate together, talk about who knew what and what they were most comfortable with and then assign them to those tasks accordingly," "We had to take some time to adjust and*

get to know what both sets of teams needed. It was really about communication. We needed to make sure work would be split in a way we all agreed with," and *"…dividing tasks was natural. My partner would start part A, the other would start part B—we would just keep asking what others needed and keep moving forward. In my partnership we decided whoever was more confident would work on the computer and the other on the circuit, but we would switch it up."*

4.c Experiential Group Learning—Preparation in Professional-Style Learning Setting

Group learning via the flipped classroom supported students' preferred way of learning and cultivated professional skills (see Table 3). Students predominantly perceived group learning in a flipped classroom as a way to develop skills and prepare for their future professions (i.e., developing and using interpersonal skills, collaboration, discussion techniques, and group-regulation of learning). A majority of students (88%) reported that they were comfortable working in their group, and 61% reported that the interpersonal skills that they developed and refined through the group work process would be valuable for them when searching for future careers. Students perceived the purpose of working in pairs as an important opportunity to learn and practice skills that reflect real world industry environments, which typically involves teamwork (e.g., *"It is important* [to be able to work in teams]. W*hen you are in the industry,* [you are] *typically* [working] *in a group setting for many projects"* and "*I think you have to learn how to manage … With four people you have to work as a team and learn team building skills. It helps as far as engineering—where you are going to be working in a team* [professionally].").

Table 3
General Perceptions of Group Learning*

Statements	% Agree
I was at ease when working with my lab partner in larger combined groups.	88
The interpersonal skills I developed through group work are valued by companies I am likely to work for.	61
The topics covered during my group interaction were just as relevant and useful as the ones covered in pairs or alone.	60
Group participation in this course provided me with time to learn to work with others to collaborate and share ideas.	59
Participation in a group situation in this course was relevant to my professional learning.	56
I received support from group members when I implemented something I learned or discussed during group meetings.	56
I am the type of student that learns well with group-regulated learning.	54
I prefer to set my own learning tasks and goals.	42
Taking a course using group work has provided me with more opportunity to receive feedback.	40
My understanding of the topic increased as a result of participation in group learning.	40
Using group work has provided me with better opportunity to learn content.	35
Working in groups helped me to learn content and concepts.	34
Taking a course using group work was more difficult than taking an instructor-directed course.	21
In the future, I would prefer to take courses using instructor-directed learning instead of learning in a group.	18

*n=68.Percentages include students who responded "Agree" and "Strongly Agree" on a 6-point Likert-type scale.

Data also revealed that over half (54%) of the students noted that they learn well in a group-regulated learning environment and that this practice met their needs. Many students noted the advantages of working with a partner and/or in a group, including *"[the ability] to divide the workload and maximize on [other's] strengths," "It allows for collaboration, so when you don't understand you can bounce ideas off another individual,"* and *"…the reports and experiments are fairly in-depth, so it is a good amount of work that … people [can] comfortably split."* Observations confirmed students' responses of sharing responsibilities with one another and a heavy reliance on their peers for trouble shooting and problem-solving.

When queried more specifically about this class, the majority of the students reported they preferred learning in a group rather than in an instructor-directed setting (82%). In addition, over three-quarters of students (79%) noted that group work was not any more difficult than an instructor-directed course. Less than half of the students, however, indicated that group work facilitated better learning opportunities (40%) that helped them understand the concepts (35% and 34%). This indicates there may be learner variables or characteristics confounding student responses and should be further investigated.

4.d The Role of Online Video Lectures

Online video lectures were implemented in place of traditional in-class lectures for students to view on their own time. The use of the lectures was completely self-directed by the students; videos were posted for students for each assignment and were accessible all the time. Students mainly used the online video lectures for knowledge rehearsal and clarification of conceptual information first learned from hands-on experimentation. Students expanded on their reasoning for using the video lectures for these purposes through interviews stating: *"I really only used them when I was doing the homework. Some of the topics you cannot really Google. They a little abstract. I felt that is when the lectures helped out," "…if I was still confused then I would watch the video," "Usually I read the Power Point and when I found something to be unclear I would go to the video lectures," "I looked at them often, especially around quizzes or if I was writing the lab report,"* and *"For me, I primarily watched the video before I did the homework."*

Table 4
Frequency of Online Video Use*

Students used online videos to…	% Agree
Review when studying for quizzes/tests	54
Clarify conceptual information	46
Extend learning	22
Prepare for upcoming labs	19
Guide them through lab assignments	16
Assist in writing lab reports	13

*n=68. Numbers represent percentages of participants who responded "often"/"most of the time."

A smaller percentage of students indicated using the video lectures to support them in preparing for the labs as well as using them as a way to extend learning outside the concepts needed for the course. Several students interviewed reported watching every video because they found them

valuable in assisting with homework and in studying for exams (e.g., *"I am pretty sure I watched all of them. I usually watched them once, and go through the PowerPoint's as I did the homework."*; *"I usually* [watched the videos] *the day before* [lab]. *Before class I would take two hours to go through and take notes"*; and *"For almost every experiment I would use them."*

In Spring 2013, students demonstrated more of an acceptance in learning with online videos than in previous semesters. By the end of the semester over half (53%) of the students indicated they were comfortable using the online video lectures in place of the traditional lecture (e.g., *"I like that you were able to take notes at home then come in and practice. If colleges could do every class like that it'd be great."*) and 56% preferred using online videos rather than having a formal lecture (see Table 5). Student responses revealed an emerging acceptance of the flipped classroom approach by many students. This is supported by the response that only a quarter (25%) of students reporting using video lectures was more difficult than attending a traditional lecture-based course (e.g., *"sitting at home with course content was difficult for me … for me personally I would prefer a lecture because it's a lot to watch after school"*).

Table 5
Perceptions of Online Video Usage*

Statement	% Agree Post (n=68)
I was comfortable when using online videos for learning.	53
I prefer a formal weekly lecture instead of online videos.	46
Taking a course with online videos allowed me to self-direct my learning.	44
I am the type that learns well with online videos.	30
Taking a course with online videos provided more opportunity to learn content during class/lab.	29
Taking a course using online videos was more difficult than taking a traditional lecture-based course.	25
Taking a course with online videos allowed for increased interaction with the instructor during class/lab.	24
The skills I developed through online video resources are valued by companies I am likely to work for.	16

*Numbers represent percentages of participants who responded "Strongly Agree"/"Agree" on a 6 point Likert-type survey.

Twenty-nine percent of the students reported that online videos allowed them increased opportunity to focus on and learn the course concepts during class time. Approximately one-quarter (24%) of students also perceived the online videos as a way to allow for more interaction with the instructor during the class time. External observations supported this in their documentation of the instructor and TAs presence and engagement with students to assist in answering inquiries and comments throughout scheduled hands-on laboratory time.

4.e Benefits and Limitations of the Flipped Classroom Approach

Flexibility of use and access was the predominant benefit for the implementation of online video lectures. Students indicated that the flexibility of the video lectures allowed them to work at their

own pace, and watch the lectures when they had time (e.g., *"It allows you to go at your own speed which is very nice! Some people grasp concepts at different paces."*). In addition, students noted that the video lectures were helpful because they provided the ability to revisit, fast forward, and rewind topics as needed and the topics were broken down into manageable sections (e.g., *"I could watch them any time. It was not a scheduled block—I could do it at ten at night, first thing in the morning….I could go back through; if you* [were] *in lecture you couldn't go back and* [review]*."*). Students also reported that the use of online videos for lectures allowed lab time to be strictly allotted to hands-on work were they could get assistance from the professor and TAs, thus providing students with the opportunity to apply conceptual knowledge gained through hands-on experimentation in class to the theoretical knowledge presented in the videos. (e.g.,*"…*[the] *video allowed you to watch it whenever you wanted. Most classes like this have a lecture and hands on part. However, it was nice that we could dedicate a whole class to a lab with the TAs help and then do the lectures when they fit my schedule was a great approach."*).

<u>**Table 6**</u>
<u>**Benefits and Limitations of Video Lectures From Students**</u>

	Student Responses
Benefits	• Anytime access/re-access • Work at own pace • Helped understand new concepts • Provided more class/practice time • Helped study for test/quizzes and homework • Extended the topic
Limitations	• More time • Lost motivation/attention • No way to ask questions • Challenging to learn from • Videos not complete/have errors
Suggestions for future	• Include captioning • Make videos more exciting/provide more examples • Provide lectures and videos • Make the videos more accessible

Limitations reported by students about the use of the video lectures were mainly concerned with not having enough time to watch the videos, not having the professor present to receive a direct response to a question, need for some enthusiasm/excitement in the videos, and the organization of the videos on YouTube (e.g., *"The one thing that I found troubling at times was if there was something I did not understand, the professor was not right there. I just could not get immediate feedback. I had to write it down and ask the questions later,"* and *"Formatting on YouTube was hard to find which video I needed"*).

Students reported limitations represented conflicting opinions, however, as some students found the organization of the video lectures problematic, while others indicated the organization was clear (e.g., "*Organization could be better. Maybe if it had a playlist…for each experiment* [each experiment <u>did</u> have a playlist]*,*" *"I would not say there were really any barriers. There was*

nothing so terrible about them that made them not worth watching," and *"…it was pretty easy to find everything. I don't think it could have been any easier. The professor did change it this semester so there is a direct link so it's easier for students to get to."*). It is likely that the ability of students to use the materials varied more than anticipated. In addition, although some students found not being able to ask questions during the video lecture a limitation, students others noted that the instructor was available via email to answer any questions students had (e.g., *"Can't just directly ask a question and get a response but I could always email him."*). These conflicting findings may indicate specific variations in learning style and preference for individual students.

When queried as to what the students would change about the video lectures, the students' responses again were mixed. For example, some students indicated watching the videos should be a requirement, while others found that having them as an option was more helpful (e.g., *"I think that if there was a way to ensure that every student actually watched the videos it would be more helpful."* and *"…I just did not have enough time to watch them all, and being able to pick and choose decreased my level of stress!"*). In addition, some of the students reported that the videos complimented the handouts appropriately, while others still responded that they would prefer a quick lecture at the beginning of class (e.g., *"[The video lectures]* were a good complement to [the] handouts. It gave me the opportunity to do my own research." and "I don't think they are needed. I think a quick 10 minute lecture would be easier in this case for the information we need."*).

The authentic experiential learning and collaboration that occurred through group learning emerged as the primary benefits for learning in a group-oriented flipped classroom setting. While noting some deficiencies, the majority of students indicated they would not change anything about the group learning process in the class.

Pedagogical benefits to the flipped classroom approach included the hands-on authentic learning facilitated by the group learning, the student-centered learning strategies used to promote deeper understanding and knowledge retention, and the formative assessment from the instructor or TAs that allowed for clarification and informed the instructor of any misconceptions that needed to be addressed as a whole group.

Table 7
Benefits and Limitations of Flipped Classroom Approach

	Student Responses & Observation Details	
	Overall Benefits	**Overall Limitations**
Pedagogy	• Hands-on, authentic learning • Mini in-class lecture provides direction and understanding for students • Guided inquiry through handouts kept students on track • Formative assessment from TAs—checking for conceptual understanding • Student-centered, student-directed	• Self-regulated learning may not be ideal way for all students to learn • TAs and instructor only interacted with a group if the group directly asked for assistance • TAs not always accessible—assisting others • TAs sometimes provide students with answer, rather than guide them

Group Learning	• Made work easier—could share tasks • Increase understanding of concepts • Increase communication/share ideas • Helped in fixing mistakes • Communication was key for successful collaboration and problem-solving • Support from TAs and instructor available upon student request • Engagement of students—teaching and asking questions of one another (depending on team interaction style) • Delegation of tasks within groups (depending on team interaction style) • Utilization of different perspectives and strengths their peers within the groups Increase communication/share ideas • Made work easier/more efficient • Increase understanding of concepts • Helped in fixing mistakes	• Too many people—created conflicts, limited equipment use for all students • Hindered learning experience • Created more stress; enjoy working alone • Within group roles rarely changed in some patterns of implementation • Even in a group of four, many continued to work in pairs (depending on team style) • Not all students within a group have equal opportunities to take part in tasks, generally due to their group dynamic. • Not all students are actively involved—missing out on valuable information • Not all students are receiving the help/guidance they need to succeed in the activity, causing them to get frustrated • Are the handouts sufficient for pushing students to the next level of their learning
Student suggestions for group learning in the future		
• Improve labs/homework/equipment/handouts—assign less labs, but make them more in-depth/intensive • Professor should provide a lecture—making for a more structured class		

Overall benefits for group learning primarily consisted of collaborating ideas, sharing tasks, communicating, and having the reassurance of another person to check over and confirm completed work. Group learning was reported to be a positive experience by students and observers in that they were able to share ideas and discuss problem-solving solutions. Noted strengths of group learning included collaborative hands-on, authentic learning, as well as development and use of communication skills to assist in the problem-solving process with multiple people (e.g., "…*you could build off each other and throw ideas back and forth,*" and "*I could ask for ideas from my group members and they could help me.*"). When queried as to how students' participation in the projects impacted their learning in the classroom, specifically within their dyads and groups, many reported increased participation in comparison to a lecture-based class, increased involvement, and improved understanding of the material (e.g., "*I think having a partner really helped me. I learned the hardware, some of the software, and what the experiments mean. I also think it really helped me go into the tests with an understanding of* [what] *the material really means,*" "*…you could build off each other and throw ideas back and forth,*" and "*I could ask for ideas from my group members and they could help me.*").

Interviews with TAs also revealed insight into student learning. TAs reported that group work enabled students to learn from one another while working with authentic data (e.g., "*Having real time data, the reason they have the mobile studio is so they can get more spontaneous hands-on learning and get them to learn for the* [sake] *of it, you can't do that in a theory class.*"). The TAs indicated this classroom set up was a valuable experience for the students since it provided vast amounts of time to apply theory to real-life scenarios and the benefits of collaboration (e.g., "*Learning from each other—learning how real systems work and working with your hands is a skill in and of itself.*").

Some evidence provided by students and documented through observations was considered both a benefit and a limitation in terms of student learning. Observation data indicated that in some student groups, students did not change roles from one assignment to the next (i.e., the same person always completed the hands-on circuit building while another always completed the computer simulations). This consistent task delegation was both a possible benefit (in professional settings, team members typically are assigned the tasks in their expertise with each project) and hindrance for students (as a learning setting, they never experienced the opportunity to develop new skills or an understanding in another area). Several students noted the benefits of consistent task delegation to be helpful and relevant to the process of learning in teams and allowed students to better utilize team members' skills to work efficiently (e.g., *"With my partner we* [divided the work up], *I was better at circuits so I did more of that, he would do more simulation and that worked for us."* Student-reported limitations of working in a group, however, included concerns with missing out on certain learning experiences (e.g., *"…*[one person can] *shoulder all of the work, but if you're in a good group than the responsibility is equally dispersed and someone will help pick up the slack and vice versa."*).

In previous semesters, a potential concern for students was their perceived lack of ability to adapt to a student-directed learning setting; after receiving student feedback, the instructor implemented a short 5 minute in class "check-in" and mini-lecture by the instructor. This provided direction or information from the instructor that allowed students to develop confidence and gradually adapt to a self-directed learning environment.

Overall, when queried on suggestions for the group learning process, the majority of students reported that they would not change anything and would keep it the same. Of those who did offer feedback, some reflected on the assignments (e.g., *"slow the pace of the experiments/projects," "Less labs, but more in-depth labs,"* and *"Stay with groups of two…larger projects can be handled a lot easier with small groups (two to three people)."*). Only a select few of the students indicated that they would still prefer to have more of a teacher-directed lecture (e.g., *"Half the time have lectures, half the time labs"*) instead of solely group learning, a notable decrease from previous semesters. This may be reflective of students' increasing comfort level with the flipped classroom as technology progresses and multimedia use increases at all levels of education.

Conclusions and Continuing Refinement

Results indicate that the flipped classroom approach was successfully implemented and supported multiple learning styles, as well as instructional preferences (direct learning via videos, guided inquiry, experiential learning, and independent and group learning). Improvements and modifications were made after each implementation in efforts to determine and maximize the benefits of using this approach for STEM learning. Flipping a classroom is a continuous process and must be investigated as such to determine variables related to student learning and the flipped classroom approach including the content itself, the age level of the students, the technology and methods used to implement the approach. This study provides a look into the process of implementing a flipped classroom in STEM higher education. The constructivist learning continuously modified within the flipped classroom in this study created student-directed learning opportunities and promoted skill development in learning, as well as professionalism. Specific skills included: the development of collaboration and communication

skills, knowledge retention of material, and increased affective variables related to learning (i.e., motivation and efficiency).

For the first time since implementation, in Spring 2013, students demonstrated an acceptance in learning via the flipped classroom approach. The majority of students indicated they would not change anything about the group learning process in the flipped classroom. Students noted limitations to learning; individual learning characteristics appeared to have an effect on student perceptions of learning in a flipped classroom. Overall, the format of the flipped classroom within the course (i.e., hands-on group work) increased students' knowledge retention in course material and increased affective characteristics related to efficiency and motivation.

All course components are being continually improved and studied. Recent changes include a more formalized approach to in class interactions between students and staff with rubrics to assess both the quality of student learning and engagement in the course. Online homework is being updated and new modes of interaction outside of class are being implemented using tools like *Piazza*. Most students report having previous experience with *Piazza* and initial use appears to be going well. At present, the average response time for student questions is 33 minutes.

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