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Transition to New Personal Instrumentation in a Flipped Classroom

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Transition in New Personal Instrumentation in a Flipped Classroom

To address the need for collaboration between academe and industry, including the ever-increasing demand of discovery and innovation in science and engineering, the National Science Foundation (NSF) sponsored the establishment of the Smart Lighting Engineering Research Center (ERC) at Rensselaer Polytechnic Institute (RPI)[1]. The education component of the Smart Lighting ERC addresses university and pre-college level education and outreach and has as its goal the development of innovative curriculum and instructional practices that will allow for transfer of new knowledge into the classroom. Although the major focus is on content related to the ERC, methods that apply to all STEM areas are under consideration in practices related to design, implementation, and assessment of student learning. Two primary goals of the Smart Lighting ERC's Education and Outreach components are to: 1) investigate the viability of alternative approaches to instruction that will build on the constructionist/constructivist approach to STEM education[1-4] and, 2) help students learn to work in professional teams that, when given a task or problem, can collaborate to provide a solution. To meet these goals, the instructional practice of "flipped classrooms" is being developed, piloted, and implemented in conjunction with other strategies that focus on self-regulated, collaborative group work at RPI.

The flipped classroom approach was first piloted in an electronics course at RPI, Electronic Instrumentation in 2009-10. Electronic Instrumentation is a survey course serving students pursuing engineering and science majors other than electrical engineering. The course includes direct hands-on application of theoretical concepts; it typically consists of two sections of 50-70 students that meet twice a week (two hours each session). Originally, the course had a common two hour lecture offered each week with separate lab times staffed by teaching assistants. Beginning in 2010, video lectures and supporting materials covering important theories, concepts, and demonstrations related to the course were created and placed online for students to view on their own time in place of the in-class lecture. Use of class time was refocused to emphasize hands-on, experiential practice of the course material using student-directed learning in groups of two and four. Under the new model, the instructor and teaching assistants (two to three per section) serve as facilitators within this hand-on learning time, and technology supplements of videos and linked resources are available to students to use outside to direct or support their in-class work. In class curriculum activities consisted of eight experiments designed by the instructor to be completed in groups of two (i.e., a dyad), supported by four projects utilizing in-depth application of materials.

Student feedback and evaluator observation of pilot use in 2010-2012 and implementation in Spring 2013 assisted in material development and the refinement of the approach. The purpose of this report is to present findings from the implementation of the approach in Fall 2013 and Spring 2014, during which new assessment techniques and learning methods (e.g., guided note supplements and search tags for the lectures) were introduced in efforts to improve student learning and the utility of the approach. Throughout Fall 2013 and Spring 2014 there was continued refinement of the online video lectures and implementation of the flipped classroom. Much of the focus is now turning to sustaining the flipped classroom pedagogy with each new class of students.

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[1] NSF Grant #0120642, 0607081

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 • Formative assessment techniques implemented	105	103	8	29
2012-13	Refinement	• Additional learning opportunities developed • User-friendly features added to online videos • Refinement of formative assessment	128	138	21	37
2013-14	Refinement and Sustainability	• Refinement of online videos and supplementary material to maintain flipped classroom environment with new technology	115	126	7	26

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

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 video is approximately five minutes in length and covered key areas of theoretical and content knowledge. A constructivist approach to problem-solving was implemented.[3-6] 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.

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" (TPS) 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.

Throughout Fall 2013 and Spring 2014 there was continued use of the TPS questions at the beginning of class, as well as using them to facilitate discussions. In addition, the instructor incorporated additional steps for students to follow during each experiment to ensure they understood the learning outcomes expected of them. An option of extra credit was offered to students who posted questions on YouTube and a discussion board to allow them to receive clarification and further their learning. During the spring, a new mobile hands-on hardware was implemented in place of the Mobile Studio, Analog Discovery. Based on the implementation of the new hardware, new videos were developed by the instructor and placed on *YouTube* to provide students with the relevant information about the new device they began using in class for their assignments. In addition the experiments and projects were rewritten to accommodate the new device. The other supplementary resources available to the students were also updated to reflect the integration of the new device.

Methodology

A mixed methodology quasi-experimental design was used to investigate the effect of flipped classroom variables on student learning outcomes. Both quantitative and qualitative methods were employed.

Student participants

Students were primarily undergraduate mechanical or dual mechanical engineering students. Students preferences for instruction and learning styles corresponded with the structure of a flipped classroom; students preferred a more visual and active approach to learning via hands-on experiments and demonstrations. Over 80% were male, more than three-quarters were white and across both semesters between 15-20% represented ethnic minorities. Approximately 10% of students reported a native language other than English. Students' learning style information revealed that the majority of students utilized visual and sensing approaches during learning. Two-thirds of the students reported a preference for a sequential approach to learning; over half used an active approach for learning. Students also reported higher preferences for modes of instruction that represented their learning styles. For example, students indicated a preference for receiving case studies, examples, and instructor demonstrations, as well as completing hands-on experiments and simulation assignments.

Table 2
Student Demographics*

Discipline of Study	%			
	Fall 2013		Spring 2014	
	Major	Minor	Major	Minor
Mechanical Engineering	78	0	63	0
Aeronautical & Mechanical Engineering	17	0	22	0
Dual—Mechanical & (DIS, etc.)	5	0	10	0
Other Engineering	0	7	5	7
Other**	0	93	0	93
Degree Progress	%			
Undergraduate year 1-2	3		32	
Undergraduate year 3-4	97		68	
Graduate	0		0	
Gender	%			
Male	83		81	
Female	17		19	
Ethnicity	%			
White	77		85	
Asian	13		8	
Hispanic	5		2	
Black	0		1	
Other	5		4	
English Primary Language	%			
Yes	90		91	
No	10		9	

Discipline of Study	%			
	Fall 2013		Spring 2014	
	Major	Minor	Major	Minor
Age	%			
18 and younger	0		0	
19-20	82		53	
21-22	18		47	
23 and older	0		0	

**Numbers represent percentage of students responding to pre-survey. Fall 2013, n=41; Spring 2014, n=74.*
***Other included: economics, product design, sustainability studies, etc.*

Affective instrumentation

The following is a summary of the data sources and collection methods used for the affective component of the paper. Pre-course surveys of students enrolled in Fall 2013(n=41) and Spring 2014 (n=74) were assessed for potential confounding learner variables represented by student demographics (e.g., academic status, academic major and minor, gender, ethnicity, English as primary language, GPA, and SAT scores). The Index of Learning Styles (ILS)[2] was included on the pre-course survey (Fall n=41; Spring n=74) to assess students' preferences toward learning styles. Classroom observations (Fall n=14; Spring n=12) documented use of group work; four randomly selected dyads in each section of the class were observed each semester (8 dyads in the Fall; 8 dyads in the Spring). Observations were used to document procedures and practices within three types of learning interactions (i.e., autonomous, partner, and group work). Post-course surveys in the Fall (n=59) and Spring (n=67) assessed student perceptions of the use of online video lectures and required group work. This included self-reported frequency of use, attitudes toward the process, as well as facilitators and barriers to the flipped classroom approach. In addition, post-course interviews with students (Fall and Spring n=6) and TAs (n=1) assessed the perceived impact of cognitive and affective outcomes of group work within the flipped classroom.

Formative and summative assessment methodology

For several years, the overall course grade has been determined from the following:

- 8 Experiments (teams of 2): 25%
- 4 Projects (teams of 4): 25%
- 8 Homework Assignments (Blackboard LMS) plus daily quiz based on short video: 10%
- 4 Quizzes: 35%
- Participation: 5%

All experiment and project information is posted on the course website before the first day of class as is all information necessary to answer the daily quiz questions. Homework questions are only available one week before their due date and remain available until the end of the term although for reduced credit. Homework questions are similar to quiz questions except that they occasionally involve tasks that require simulation or other tools not available at quizzes.

Results

Experiential group learning as a support to flipped classroom

To support the flipped classroom approach to teaching and learning, the instructor implemented a hands-on collaborative learning environment that focused on student-directed group work; this approach was used instead of the in-class lecture/lab methodology. As part of this approach, the instructor developed lab assignments (experiments and projects) which required working in dyads and groups of four, which required students engage 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.

Learning the dynamics of collaborative, group-directed learning

Data revealed that, in the flipped classroom, when students worked in collaboration for decision-making processes needed for planning the execution of lab assignments and when completing assignments, both collaborative and cooperative groups emerged. Despite differences in group structure, communication was noted by all as the key element for success. Initiative and direction taken by students supports the flipped classroom approach.

Table 3
Primary Decision-Maker by Activity*

Activities	Decision-maker											
	Instructor		TAs		Team Leader		A member of my team		My team as a group		Decided myself	
	F'13	S'14	F'13	S'14	F'13	S'14	F'13	S'14	F'13	S'14	F'13	S'14
Setting the content of the lab.	80	89	0	3	2	2	2	1	14	5	2	0
Establishing short-term goals.	22	18	4	0	13	9	11	6	44	59	7	8
Dividing the tasks.	0	0	0	0	9	9	13	11	75	77	4	3
Documenting progress.	0	3	2	2	7	9	18	21	66	63	7	2
Deciding to move on to the next task.	2	1	4	2	5	9	11	14	66	69	13	5
Completing the lab write-ups.	2	0	0	0	5	5	7	12	79	82	7	1

**Numbers represent the percent of students who selected the decision-maker for each activity on the post-survey. Fall 2013, n=59; Spring 2014, n=67.*

Student self-report was further supported by external evaluator observations that revealed, overall, most groups divided tasks amongst members to form a cooperative effort or they completed each step as a collaborative team before moving on to the next. Documentation suggests that often, collaboration in completing each step together more often occurred during dyad work. Students interview responses confirmed observations, e.g., *"As a team we would go sequentially through laying everything out as we go," "We had a set time [during the week] in the library and then we divided up the work and in the last page of the lab manual we divided the* *several parts,"* and *"I knew my partner … and we worked together on all aspects."* When queried on the relevance, and success, of group work, students and teaching assistants noted that the ability to communicate with others was essential for groups to divide and share the workload appropriately, as well as to discuss and ensure understanding of the assignment at hand (e.g., *"Working with others was really beneficial because they would catch my mistakes," "I could get immediate feedback when I had a question," "[group work] was nice because we could toss ideas around and figure things out together whereas when completing things individually you would have to Google things or find other ways," "Communication was really helpful and relevant because we needed to collaborate," "having more eyes on the same problem … it was good to talk things out and troubleshoot,"* and *"[group work] allows [students] to learn how to delegate responsibilities within a team while also keeping one another motivated and taking advantage of one another's unique strengths."*).

Increased Efficiency and Participation

Flipped classroom collaborative groups also were shown to facilitate the effectiveness of the active experimentation and increased student knowledge of the concepts covered in the group setting. Student reported that working in a pair or a group was beneficial in providing multiple perspectives when solving problems and in dividing the work for efficiency purposes (e.g., *"By working with another team as well as my partner I got two additional perspectives," "…beneficial to have more people … to bounce ideas off of and split the work load," "It's nice to toss ideas around and figure things out together,"* and "*"I really liked working with the other team just to get an added perspective."*). Students noted the importance of working collaboratively to plan assignments. Students who formed a cooperative group structure to complete work, initially collaboratively set up roles (whether intentional or not) to divide the work for increased efficiency and insurance of participation from all team members (e.g., *"We split up how we saw fit utilizing everybody's strong suit … [one person] was good at PSpice, two other were good at reports and building the circuits,"* and *"Everyone always had something to do,"*).

Preparation in professional-style learning setting

Student responses not only revealed an acceptance and preference for active group learning in a flipped classroom, they also showed an awareness of the importance of skills cultivated via experience within the flipped classroom as having an impact on their future professional career.

Table 4
General perceptions of group learning*

Statements	% Agree	
	Fall 2013	Spring 2014
	Post (*n*=59)	Post (*n*=67)
I was at ease when working with my lab partner in larger combined groups.	82	82
The interpersonal skills I developed through group work are valued by	70	75

Statements	% Agree	
	Fall 2013	**Spring 2014**
	Post (*n*=59)	**Post (*n*=67)**
companies I am likely to work for.		
Participation in a group situation in this course was relevant to my professional learning.	63	64
I received support from group members when I implemented something I learned or discussed during group meetings.	59	54
Group participation in this course provided me with time to learn to work with others to collaborate and share ideas.	54	62
I am the type of student that learns well with group-regulated learning.	48	36
The topics covered during my group interaction were just as relevant and useful as the ones covered in pairs or alone.	48	51
My understanding of the topic increased as a result of participation in group learning.	45	32
Using group work has provided me with better opportunity to learn content.	36	31
Working in groups helped me to learn content and concepts.	36	38
I prefer to set my own learning tasks and goals.	34	36
Taking a course using group work has provided me with more opportunity to receive feedback.	34	33
In the future, I would prefer to take courses using instructor-directed learning instead of learning in a group.	29	13
Taking a course using group work was more difficult than taking an instructor-directed course.	18	12

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

As noted in Table 4, students reported perceptions of group learning in a flipped classroom to support their development of professional skills. Student's perceived the flipped classroom to foster and refine interpersonal skills (70% Fall; 75% Spring) and reflect authentic real world environments (63% Fall; 64% Spring) they will be exposed to in their future careers. The majority of students (82% Fall & Spring) indicated they were comfortable, and felt supported when working in a collaborative group. More students in the spring (87%) indicated they would prefer learning in group settings over instructor-directed settings than did students in the fall (71%); however, more students in the fall (48%) reported having self-confidence in learning in a group than did students in the spring (36%). The varied responses were not so substantial, however, since the majority of students continued to prefer group learning over instructor-directed courses. Over 75% of students (82% Fall; 88% Spring) perceived group work in the flipped classroom to be easier or have the same difficulty as taking an instructor directed course. Although most students indicated more of a preference for group learning environments, less than half of the students indicated a preference for the self-directed aspect of the flipped classroom, as well as the perception that the setting provided greater opportunity for learning the content. This may be indicative of confounding variables of the learners and their typical learning environment.

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 reported primarily using the online videos for knowledge rehearsal and clarification of concepts (e.g., *"I would only watch for homework and maybe for quizzes," "It allowed me to have things re-explained numerous times,"* and *"I used them specifically to study for the quizzes"*). Students also noted using the lectures to extend the learning that was occurring from the in-class, active experimentation (e.g., *"I really only watched them when I had a question and then I would skip through the video"* and *"Helped [me] understand concepts"*). Although less frequent, approximately 10-20% of students also indicated using the videos as a guide for lab assignments and to prepare conceptually for upcoming labs (e.g., *"[Used] every week before class, before experiments"* and *"…help[ed me] understand what I need to do in the experiment."*).

Table 5
Frequency of online video use*

Students used online videos to…	%	
	Fall 2013	**Spring 2014**
	Post (*n*=59)	**Post (*n*=67)**
Review when studying for quizzes/tests	52	63
Clarify conceptual information	33	45
Extend learning	22	27
Assist in writing lab reports	22	13
Guide them through lab assignments	16	18
Prepare for upcoming labs	10	12

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

Table 6
Perceptions of online video usage*

Statement	% Agree	
	Fall 2013	**Spring 2014**
	Post (*n*=59)	**Post (*n*=67)**
I prefer a formal weekly lecture instead of online videos.	63	46
Taking a course using online videos was more difficult than taking a traditional lecture-based course.	46	32
Taking a course with online videos allowed me to self-direct my learning.	39	43
I was comfortable when using online videos for learning.	36	45
Taking a course with online videos provided more opportunity to learn content during class/lab.	25	28
The skills I developed through online video resources are valued by companies I am likely to work for.	20	10
I am the type that learns well with online videos.	18	18
Taking a course with online videos allowed for increased interaction with the instructor during class/lab.	14	24

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

Overall data on student perceptions of online video lectures revealed that there was some variability in responses between semesters. In general, less than half of the students reported that using online video lectures was more difficult than taking a traditional lecture-style course. This demonstrates, and supports, the emerging acceptance of a flipped classroom approach that was initially reported in the Spring 2013 report. Some variation in responses is noted between semesters. In general, students reported more positive perceptions in the spring. Over half (54%) of students preferred using online video lectures rather than having to attend traditional lectures (compared to 37% in Fall 2013). In addition, 45% of students in the Spring and 36% of students in the Fall reported they felt comfortable using online video lectures to learn from.

Student responses on self-direction also supported the emerging acceptance of a flipped classroom approach; over one-third (43% Spring; 39% Fall) reported the use of online videos facilitated self-direction of learning. This is also supported by the response that a little over one-quarter (25% Fall; 28% Spring) of the students indicated that the flipped classroom and use of online videos allowed for more opportunity to learn the content in the lab. Approximately one-quarter (24%) of the students in the Spring also reported that the online videos provided increased opportunity to interact with the instructor during class time. Fourteen percent of students in the Fall agreed with this, again this may be indicative of variations in learner characteristics.

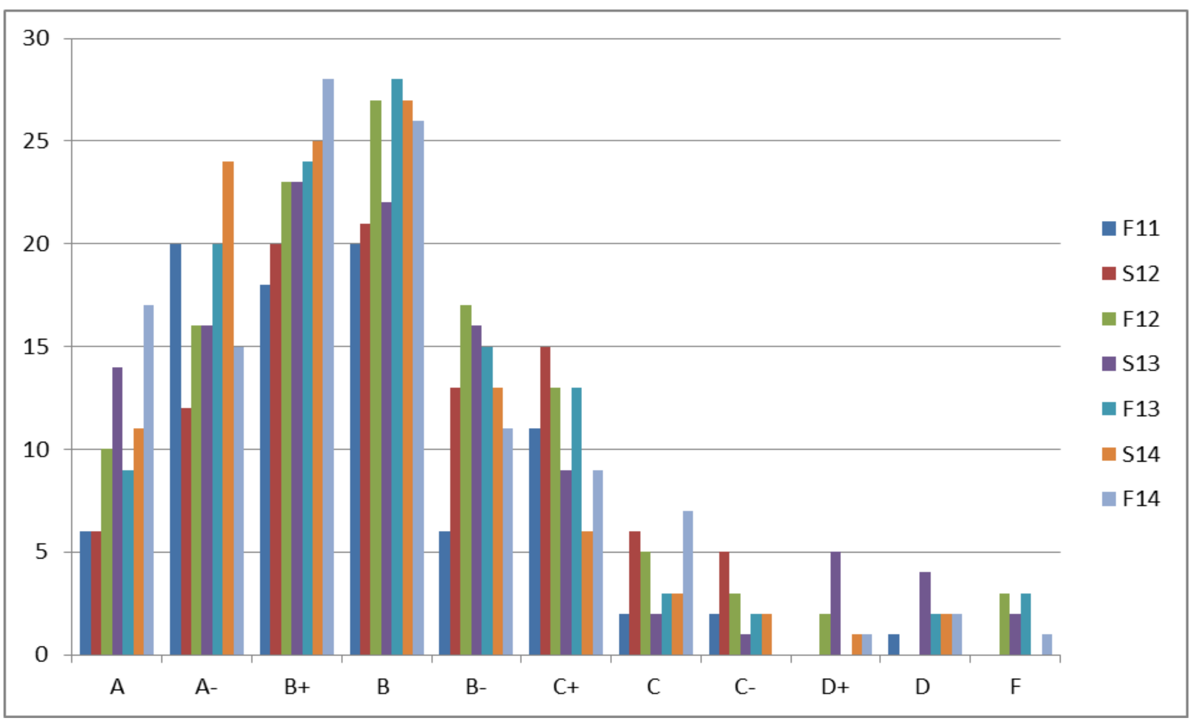
Impact of flipped classroom and supporting materials on student learning

The goal of this approach to flipped classrooms was to have very few surprises; students should know what they are to learn and should have ample opportunity to practice it. This does not mean that course materials do not change. Expectations are, in fact, constantly being updated, usually based on feedback from teaching assistants and students. Changes also occur when new tools become available that fit in with the goals of the course (e.g. using piazza to provide quick answers to student questions, to share ideas on how to do projects, for general communication with course staff, etc.).

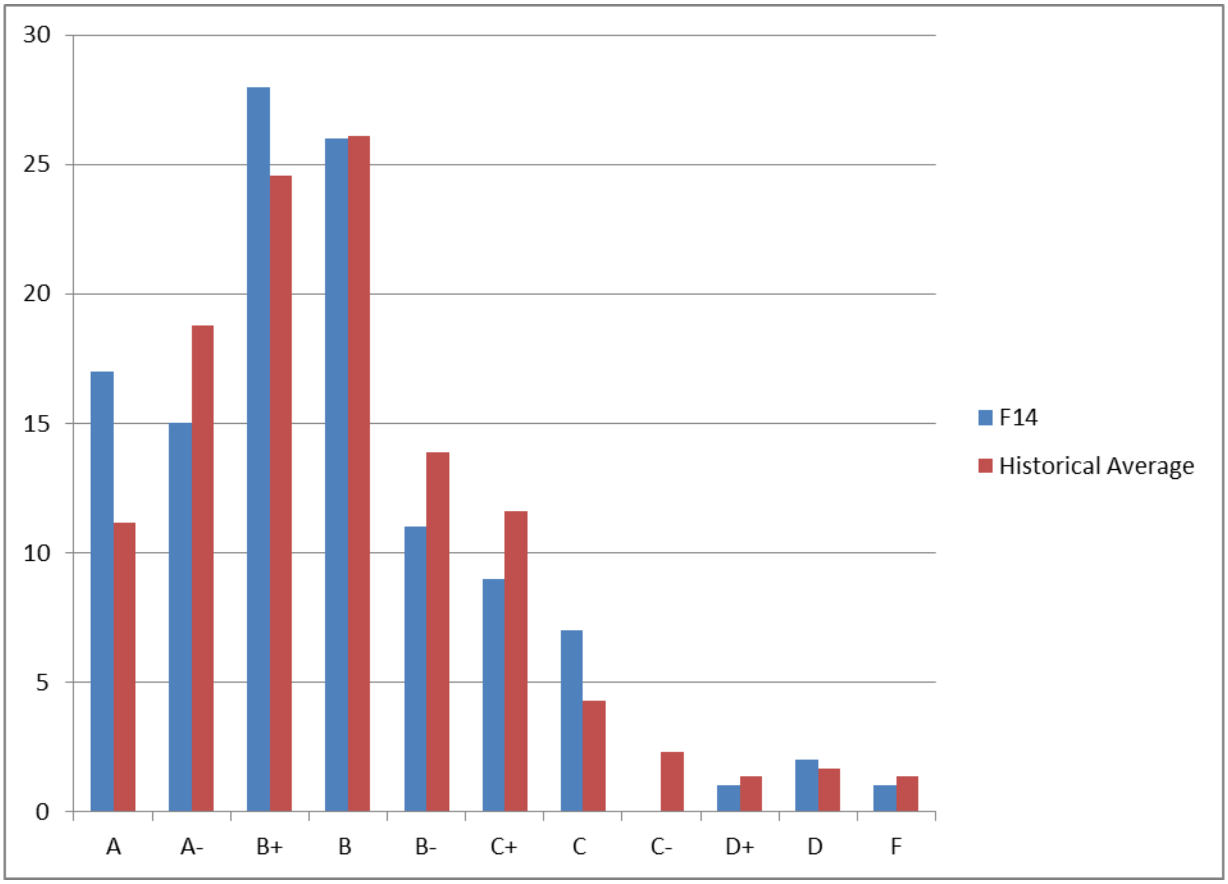
For the current study, the majority of the course grade (60%) was based on work that is or can be done by teams. Experiments and projects were done and reported on by teams, as were the daily quizzes. Homework was more often than not done by teams, but not necessarily consisting of the same people. The participation grade (5%) utilized a rubric that incorporated input from students and TAs but was determined solely by the instructor. TAs were encouraged to monitor and document in-class student preparation and performance using a simple phone app to record positive and negative points and also to do an overall assessment at the end of the term. Students evaluated their project teams and teammates twice each term. The very large amount of direct interaction between the instructor and the individual teams makes it relatively easy to assess how engaged students are. The input from the TAs and students help calibrate the instructor’s task.

The remainder of the course grade (35%) comes from quizzes. The structure we use for quizzes provides us with an excellent tool to assess whether any changes made in the course have positive, negative or neutral impact on student learning. For more than a decade, each quiz was organized into five topical areas described in greater detail on our Quiz Information web page that is available to students (see http://ei-rpi.org.) In addition to the descriptions, many example questions are provided. Also, solutions to essentially every quiz since 2007 are posted. The only differences from term to term are in the number of questions on the quizzes (usually 5, but sometimes 4) and, since fall 2014, the number of quizzes. Overtime the number of required quizzes has been reduced from 4 to 3 and an optional, comprehensive fourth quiz added that students can take to improve their grade. Only the first three quizzes are graded by the TAs. The optional fourth quiz is entirely multiple choice or fill-in-the-blank questions so anyone can grade it (i.e. volunteers from the instructor's family). The change from four to three quizzes was made because enrollments in the class are now climbing and we wished to free up more TA time so they can actively participate in piazza discussions and other new in-class activities we are trying out. Quiz grading is also as consistent as we can make it. We start with simple grade standards (A: 91-100; B: 81-90; C: 71-80; D: 61-70) and then, if necessary, adjust the ranges down slightly (e.g. use 11 points per grade rather than 10). We do this to correct for any unanticipated problems with issues like the wording of questions and use the grades from previous terms as a guide. The students are told that if everyone gets 91 or better, they will all earn an A grade (it never happens). However, in recent terms, more quiz grade distributions require no corrections.

As we have continued to refine our flipped classroom environment and, recently, switched to new personal instrumentation hardware (Mobile Studio to Analog Discovery), we have observed steady increases in student quiz and, therefore, overall course performance. The changes each term are not large, but they are significant. For context, it is important to remember that 80% or more of the students in this class do not have any great desire to learn electronics or instrumentation. They are nearly all mechanical or aeronautical engineering students and can look pretty bewildered for the first few classes.



Overall Course Grade Distributions for 7 Semesters



Fall 2014 Grade Distribution and Historical Average (Includes Fall 2014)

The two figures above show the raw data for each term and the comparison of Fall 2014 to the historical average, which also includes Fall 2014. While the grades slowly improve, there remains a persistent tail of Ds and Fs. The students in this group were followed closely throughout the term and offered additional help. Their grades remained low because they were unable to complete all course requirements. Three of the four students were having some kind of personal issues that left them with insufficient time to work on this course, but chose to complete the course and earn a passing grade rather than dropping and trying later. The fourth student was taking the course for the third time to satisfy his parents but stopped working about half way through the term. All four would have earned at least a C if they completed all requirements,

Student reported benefits and limitations to flipped classrooms

Accessibility and flexibility in viewing and learning from online video lectures were key benefits noted by students. There were variations in limitations reported by students; however, limitations appear to be influenced by individual learner characteristics.

Table 7
Benefits and limitations of video lectures from students

Student Responses		% Responded	
		Fall 2013 *n*=44	**Spring 2014** *n*=59
Benefits	Anytime access/re-access	29	13
	Helped study for test/quizzes and homework	21	33
	Work at own pace	21	25
	Helped understand new concepts	19	19
	Provided more class/practice time	5	13
	Extended the topic	2	2
Limitations	Challenging to learn from/didn't always watch them	19	40
	No way to ask questions/didn't answer questions/no feedback	36	19
	More time/no lecture time	11	9
	Lost motivation/attention	8	5
	Not relevant	0	21
	Videos not complete/have errors	0	7
Suggestions for future	Lecture only	80	74
	Make videos more exciting/provide more examples	14	14
	Provide lectures and videos	8	14
	Make the videos more accessible	8	4
	Make the videos shorter/more useful	8	10
	Make videos more detailed/more technical	3	10

Students indicated the accessibility and use of online lectures for review were the main benefits to using them in the flipped classroom approach. The flexibility allowed students to view the lectures multiple times, at any time, and provided a way for them to study and prepare for assessments throughout the semester (e.g., *"You can rewind and not have to rely on notes," "…review anytime you want,"* and *"It didn't take up lab time; …now we have all lab with TAs right there to help,"*). Some students and the TAs also noted the benefits of students directing their own learning through the use of the online approach (*"Every once in a while I'd want elaboration so I could just listen," "…Watch them at your convenience and stop/start according to your style,"* and *"Having recorded lectures helps supplement students' learning"* and "[Online video lectures] *reinforce*[s] *self-motivated learning, which is an important skill for aspiring graduate students."*).

Noted limitations of the online videos were related to students' perceptions ease of use for learning, their self-direction process, and feedback. Some students indicated the video lectures were more challenging to learn from (e.g., *"They were pushed aside until we absolutely needed them," "There weren't enough example problems that pertained to the homework,"* and *"You can't ask questions."*) and they did not always make time to watch them because they were not mandated (*"Sometimes I would just get so caught up in other stuff"* and *"It was* *difficult to make time to set aside to watch them when this is solely our responsibility"* As in all previous semesters, some students also noted the lack of immediate feedback as a limitation.

When queried as to what changes might be made, students suggested giving more examples, providing more of a mixture of video and in-class lectures, and making them more detailed. It should be noted that fewer students expressed a desire to have "lecture only" in the Spring 2014 semester than did students in Fall 2013, and after some modifications were made to the video access after suggestion in Spring 2013, fewer students in Spring 2014 suggested making the videos more accessible (e.g., *"Not really [barriers to using video lectures], they are really accessible"*).

Results of this study show that the classroom environment and structure of the flipped classroom allowed for more hands-on authentic learning. Mini-lectures, demonstrations, and handouts facilitated student understanding and provided guidance, while maintaining a self-directed approach. In addition, TAs conducted short formative assessments through checking in and asking questions to encourage deeper thinking and assess understanding before students could move on to another task in the lab assignment, as TAs noted, *"students who understand material best can explain it to [someone else]"*).

Table 8
Overall benefits and limitations of flipped classroom approach

	Student Responses & Observation Details	
	Overall Benefits	**Overall Limitations**
Pedagogy	• Authentic learning environment—hands-on activities • Mini in-class lectures/demonstrations provides information and understanding for students • Handouts provide a source of guided inquiry to help keep students on track • TAs provide formative assessments—checking for conceptual understanding • Student-centered/directed approach to learning	• Accessibility of TAs—assisting others/distracted by their own technology • Interactions with students and TAs/Instructor only occurred upon request of the students • Students may need more assistance at the beginning of the semester to get used to the flipped classroom approach

	Student Responses & Observation Details	
	Overall Benefits	**Overall Limitations**
Group Learning	• Made work easier/more efficient—could share tasks • Increase communication/share ideas • Increase understanding of concepts • Helped in fixing mistakes • Utilization of different perspectives and strengths with their peers and within the groups to help teach one another • 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) • Improved teamwork skills/interactions • Helped to stay on task	• Too many people—created conflicts, limited equipment use for all students • Made it difficult to get a full understanding • Lack of communication amongst the members • 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
Student suggestions for group learning in the future		
• Improve labs/homework/equipment/handouts—make it so multiple people need to work on the same task at once • More time for experiment and project • No teams of four—more pair work • Grading/responsibility of project—concrete roles/tasks for each member of the group • Professor should provide a lecture—making for a more structured class		

Noted benefits of group learning included the opportunity to learn from others (i.e., the promotion of collaboration/cooperation and communication), increased efficiency in completing assignments, assistance from other students to help figure out and create meaning from mistakes, and helped the group as a whole to stay on task with assignments and concepts (e.g., "*Working with others was also really beneficial because they would catch my mistakes, "I could get immediate feedback from them when I had a question,"* and "…[The] *troubleshooting process was quicker."*). In addition, depending on how the student groups structured themselves, certain groups focused on teaching one another to facilitate team members and their own understanding of material, and certain groups delegated tasks across all members or completed each task as one group (e.g. *"You factor in who is good at certain things and then have to delegate,"* and *"We work*[ed] *well together, split the workload, and complete[d] the assignments."*). All of these benefits are directly related to skills needed to function on teams in the professional world.

TAs also reported on the value of the flipped classroom for an instructor perception (e.g., *"It improves student learning outcomes and also helps keep them motivated"*). TAs noted the importance of the group work for developing student responsibility and learning via team settings (e.g., "*[group work] allows them to learn how to delegate responsibilities within a team," "[allows] them to keep one another motivated and take advantage of one another's unique strengths"*).

Student-reported limitations, supported by observation data, indicated concerns for the potential to miss out on learning opportunities depending on the structure of the group. These concerns have been noted across semesters. For instance, students noted that in some groups individuals completed the parts of the assignment they were comfortable with, and maintained these roles throughout the semester (i.e., *"…people settle[d] into tasks they were confident doing," "…We all did the same thing for each project"*). Students indicated that they felt they did not learn about certain concepts or areas of the labs as much as they might have if they had had to do all parts of the work, or had changed roles. After further inquiry, however, most students noted they would not change the structure of their group.

Analysis of student suggestions on group learning revealed that the majority of students reported they would not change anything. Several students suggested increasing the opportunity for group work (e.g., *"I would do more team projects"* and *"Have more time for four people projects"*); however, more students made suggestions to have more partner work rather than group work (e.g., *"Make it just groups of two"* and *"I like partner learning better"*). Other suggestions included giving more optional time on assignments to help teams (e.g., *"give us extra time on the first experiment/project, let high functioning teams get ahead and other problem teams are easier to notice"*), combining group learning with a form of lecture (e.g., *"It's a great learning method, but more instruction (lectures) from the instructor would be a great help."*), and to create concrete roles for team members. These less frequent suggestions directly reflect students anxiety level for learning with a flipped classroom approach; however, the infrequency of these comments supports previous semesters documentation that students may becoming more receptive and accepting to learning this way.

Conclusion

Overall, the NSF funded Smart Lighting Engineering Research Center at RPI attempt at investigating the development of innovative curriculum and instructional practices through the use of self-regulated, collaborative group work within a "flipped classroom" is proving successful. Results indicate that the flipped classroom approach is allowing students to learn key concepts outside of class via online video lectures, leaving class time devoted to hands-on practice of the concepts. The approach is also successful in the use of group work in dyads or teams of four to complete assigned tasks. Data indicate the flipped classroom approach supports multiple learning styles and preferences for instruction. Students perceived the online video lectures as a resource for knowledge rehearsal and as a means of knowledge extension. Overall, the implementation of the flipped classroom approach promoted professional development skills of collaboration and communication, and provided evidence for the benefits of constructivist learning. The format of the active experimentation 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.[7-9] Key benefits of the flipped classroom included the flexibility of use in online video lectures and opportunities to build collaboration skills. Barriers included the inability to ask immediate questions while viewing the lecture; however, the variation in response indicated the possibility of confounding individual learning characteristics.

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