120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7171

Inverting (Flipping) Classrooms – Advantages and Challenges

Dr. Gregory Mason, Seattle University

Dr. Greg Mason is an Associate Professor in the Department of Mechanical Engineering at Seattle University. His interests include control systems, data acquisition, and the use of technology to support the non-traditional classroom.

Prof. Teodora Rutar Shuman, Seattle University

Teodora Rutar Shuman is an Associate Professor and Chair at Seattle University, Department of Mechanical Engineering. She received a B.S. in Mechanical Engineering from University of Belgrade, Yugoslavia, and an M.S. and a Ph.D. in Mechanical Engineering from the University of Washington. She pursues research in electro-mechanical systems for sustainable processing of microalgae. email: teodora@seattleu.edu

Dr. Kathleen E. Cook, Seattle University

Kathleen Cook, Ph.D. is an Associate Professor in the Psychology Department at Seattle University. Dr. Cook received her doctorate in Social and Personality Psychology from the University of Washington, with a minor in quantitative methods and emphases in cognitive and educational psychology. Her research has included classroom learning, person perception, health perceptions, and jury decision making.

Inverting (Flipping) Classrooms – Advantages and Challenges

Abstract

The educational benefits of learner-centered instruction, including active, collaborative, and problem-based learning, are widely recognized. However, educators are often reluctant to implement learner-centered activities because they perceive doing so will reduce class content coverage. An inverted classroom is a method that can free classroom time for learner-centered activities. In an inverted classroom (IC), course content is disseminated outside the classroom through mediums such as video lectures and web-based tutorials, in addition to traditional methods such as assigned reading, assigned homework problems, interactive exercises, and power-point presentations. Students are responsible for learning basic course material outside of class time. Unlike an online class, an IC includes face-to-face time with the instructor in classroom or laboratory setting where the material learned outside of class is discussed and applied. The IC allows an educator to present course material in several different formats, and so engages the different learning styles and preferences of students. The IC format encourages students to become self-learners and help prepare them for how they will need to learn as practicing engineers. Our experience shows that the IC format can free class time for learner-centered activities without sacrificing course content.

This paper describes the implementation of an IC in a senior-level Control Systems course. Two offerings of these courses with 20-25 students each have been entirely taught as inverted. This paper describes best practices in offering these courses, including suggestions for instructors on preparing video lectures and structuring the course to provide a safe environment for students to learn in this unique format. Three years of assessment data are presented in this paper, including student exam performance, and instructor and student observations and perceptions of the inverted classroom format collected through surveys and interviews. Key results from assessments are: 1) although there was some initial resistance from the students to the new format, students adjusted to the format after a few weeks – the format should be implemented for an entire term in order to obtain full benefits of this approach; 2) students showed an increased awareness of the importance of self-learning and the benefit of taking responsibility for their own learning; 3) the format frees time for students to individually or collaboratively solve more problems than in a lecture setting and opens the opportunity to implement problem-based learning without sacrificing content coverage; 4) student performance on exams and homework was not diminished through the uses of an IC; 5) aside from the initial time investment by the instructor to create on-line content, the work load on the instructors and the students was not much different than in the traditional classroom; 6) the video-lectures don't need to be production quality, rather content-focused and succinct; 7) an IC should be offered with an adequate course structure, including a guide to the on-line content.

Introduction

Both the American Society for Engineering Education[1] and the National Academy of Engineers[2] have called for education reform, based on scholarly and systematic innovation that is focused on educating engineering graduates who are self-learners and problem-solvers. Numerous studies have shown that a student- or learner-centered instructional environment can be an effective means to promote such intellectual growth[3,4,5].

Learner-centered instructional methods encompass a wide range of approaches that include active and collaborative learning, problem-based learning, and project-based learning[6]. Incorporating student-centered learning into the classroom can improve student learning[6,7]; can improve student attitudes[5,6]; can be of particular benefit to those students whose personality types and preferred learning styles impair their performance in traditional educational environment[8]; and can improve students' ability to solve open-ended problems[9].

While learner-centered methods hold the promise of improved education they do have a cost. The methods require educators to make time for the learner-centered activities and so can make it more difficult to cover all the content demanded in engineering courses[10,11]. One solution to this dilemma is to deliver the course content using an inverted classroom[12,13,14].

In an inverted (or flipped) classroom (IC), course material is disseminated outside of class time; and class time is use for learner-centered activities that help clarify and reinforce concepts. Inverted classrooms in various forms have been used for decades. In the 1820s, the Military Academy required students to come to class prepared to recite results from the lessons studied the night before and to work problems on a blackboard[15]. In the 1990s instructors began using technology to disseminate lecture material[16,17]. Web-based instruction or video lectures allowed instructors to customize material and delivery to meet the needs of their students. In 2000, Lage, Platt and Treglia[18] reported on their success of inverting an economics course to address different learning styles, and recently, an IC using video lectures was successfully used in secondary education[19,20].

An IC is different from an online class because it includes face-to-face class time with the instructor; and it is more than simply requiring students to read the text before coming to class. In an IC, the material disseminated outside of class is designed by the instructor to supplement and reinforce concepts from the textbook. By moving traditional lecture material outside of class time, the IC frees that time for learner-centered activities. This was demonstrated by Zappe et al.[11]. Zappe et al. posted video lectures online for students to view outside of class, freeing time for active learning exercises during lecturing period. Bland[21] found that the IC format actually allowed more content to be covered in a course. Similar approaches have been taken by many others[14,22,23,24,25].

Another benefit of the IC is that it allows an educator to present course material in several different formats, and so address the different learning styles of students. Lage et al.[18] used an IC in an economics course, providing course material in video, text and PowerPoint formats. Their findings showed positive student satisfaction and suggest that the IC format may even be useful for attracting students. Gannod et al.[13] successfully used an IC in order to address learning characteristics common to students who have grown up with access to technology.

Yet another benefit of the IC is that is can be used to encourage students to become self-learners and help prepare them for how they will need to learn as practicing engineers. Bland[21], for example, structured an electrical engineering class using an IC to encourage students to learn independently. Course material was provided primarily in text format, instead of as video or interactive media. Students in this study noted an increase in their use of collaborative learning and an improvement in their learning skills applicable to an engineering career.

Research on the effectiveness of an IC in engineering courses has focused on two fronts: student satisfaction and student learning. A majority of the studies focus on student satisfaction and find high satisfaction with the class format. Bland[21], Haden et al.[24] and Kellogg[26] all found that students enjoyed the IC format and felt it motivated them to learn. On the other hand, studies using the IC in engineering courses have shown marginal or no improvement in student learning when comparing an IC to traditional course. Papadopoulos and Roman[14] used the Concept Assessment Tool in Statics (CATS) to compare the understanding of students from an IC and traditional statics course and found no statistically significant difference in their knowledge. Rais-Rohani et al.[27] similarly used an IC in a statics course and found no statistical difference in achievement between the IC and control group. Kellogg[26] reported marginal improvement in a construction management course, but didn't claim any statistical significance. In these studies, however, the IC was implemented for only a portion of the course in order to compare the results with a control group. An IC format, like any new learning format, takes time for student to adjust to, and so short-term use may not be realizing the full benefits of an IC.

In this paper we report on the results of a study comparing three class offerings of an upper-division engineering course in which a traditional lecture course (TC) was used one year and an IC was used the following two years. The remainder of the paper is divided into three sections – Description, Results and Lessons Learned. The Description section provides an overview of the courses used in this study, the student population, and how the TC offering differed from the IC offerings. The Results section presents results from three areas. 1) The effect of an IC on content coverage. 2) The effect of an IC on student performance on traditional textbook and design problems. Students wishing to pursue engineering licensure (Fundamentals of Engineering and Professional Engineering exams) must pass a test composed of traditional textbook-type problems. Therefore it is important that the IC not sacrifice student performance on traditional problems. 3) The effect of an IC on student's perception. The final section, Lessons Learned, summarizes the key lessons from this study and provides some practical suggestion for implementing an IC.

This paper is a continuation of the paper by Mason, Shuman and Cook[28]. The Description is taken largely from Mason, Shuman and Cook to provide context for this paper. The Results are partially based on that same reference but add: 1) new data and new results from the third year of the study, and 2) a discussion of the implementation details and insight from the instructor. The Lessons Learned provides practical suggestions for the instructors wishing to implement this approach and is entirely new.

Description

The course used in this study is Control Systems in the Mechanical Engineering program. The Control Systems course is taught over 10-weeks as a four-credit quarter-long course required of all senior mechanical engineering majors and is the students' first exposure to control systems concepts in the curriculum. Prerequisite courses include Dynamic Systems and Numerical Methods. The course covers traditional controls topics including root locus, Bode plots, Nyquist plots, PID and lead/lag controller, see Table 1.

Table 1. Control System Course Content (Planned)

Topic	*Description*
Ladder Logic	Design of simple discrete control logic using ladder logic diagrams, including use of latches
Signal Flow Graphs	Model systems using SFG. Simplifying SFG using Mason's rule. Convert between SFG and transfer functions
Block Diagram	Model systems using block diagrams. Simplifying block diagrams using block diagram algebra. Convert between block diagrams and transfer functions
Transfer Function Open Loop Analysis	Characterize the transient and steady state response of a system using parameters such as settling time, damping ratio, etc. Determine system stability. Map time domain response to complex plane
Root Locus	Sketch root locus for system when varying any specified system parameter
Proportional Control	Design of closed-looped feedback system with proportional control. Find gain directly (matching coefficients) or using root locus
PID Design	Design of a PID controller using root locus. Select appropriate controller type based on plant and specifications
OL Bode Plot Analysis	Sketch Bode plot of system. Determine stability, phase margin and gain margin. Characterize time domain response from shape of Bode plot
Bode Phase Lead Design	Design a phase lead controller using Bode plots. Understand relation to root locus design
Bode Phase Lag Design	Design a phase lag controller using Bode plots. Understand relation to root locus design
Nyquist Stability Analysis	Determine stability of closed loop system from Nyquist plots. Determine phase and gain margins
State Space	Model systems using state space. Convert between state space and transfer functions
State Space Open Loop Analysis	Characterize the transient and steady state response of a system. Calculate Eigen values
Similarity Transformations	Transform systems using similarity transformations. Diagonalize a systems with real and complex Eigen values
Controllability/Observability	Determine system controllability and observability
Full State Feedback Design	Design a full state feedback system using similarity transforms and solving for gains directly, or using Ackermann's formula

The course was evaluated in three successive years. The first year the course was taught using a traditional lecture classroom (TC); the next two years the course was taught using an inverted classroom (IC). All courses were taught in winter quarters by the same professor, using the same textbook and weekly homework assignments. The first two years the course was held four days a week with 50 minute class periods. In the third year the course was taught three days a week with 70 minute class periods.

Topics in all offerings were introduced in the same order. In all courses students were assessed using weekly 15-minute quizzes, a midterm exam and a final exam. Exams were scheduled at approximately the same time during the quarter for all courses and were as similar as possible, each having approximately the same number, type, and difficulty of questions.

All courses utilized Matlab's control system software and control system hardware developed by Quanser[29]. Students were familiar with Matlab and Simulink from a prerequisite course.

The Traditional Lecture Classroom (TC)

The Control Systems course was taught the first year using a traditional lecture format. These students served as the control group for this study. Content for the traditional course was presented using a lecture format. In a typical week, example quizzes and homework were assigned on Fridays. Students were given a quiz on the previous week's material on Tuesday. The rest of the week was used for in-class lectures followed by textbook-type and homework-type examples. Most of the examples were solved by the instructor on the board and only occasionally by students in short active learning activities. Five class periods (12% of total) were held in a computer lab where students either solved problems similar to the assigned homework using Matlab or designed a controller for the Quanser[29] hardware.

The Inverted Classroom (IC)

The second and third year of the study, the Control Systems course was taught using an inverted classroom. The course content was delivered outside of class time using short video lectures supplemented by textbook reading assignments, homework problems and example quizzes. Students were required to study course content (view video lectures, do homework, solve example problems) and come to class prepared for the daily activities.

The course videos were created using Camtasia Studio[30] and a Tablet PC. The videos included audio of the instructor explaining the material and a live screen capture of the instructor writing on the tablet. The videos were posted on YouTube (YouTube channel MEGR438) and accessible to students. To cover the course content there were 45 videos in the 2011 IC offering and 50 videos (5 additional) in 2012 IC offering, each between 3 and 12 minutes long. To achieve this length, videos were edited and shortened to approximately half their original length by removing pauses from the presentation that occurred while writing or when explaining the material. This resulted in six hours of video content posted online. Specific videos were not initially assigned for watching. Instead students were given example quizzes and, in conjunction with the assigned homework, were expected to identify and watch videos relevant to the material for the week.

In a typical week, example quizzes and homework were assigned on Fridays. Students were expected to come to class on Mondays prepared to discuss the weekly topics. Class time throughout the week was spent solving problems (except for a weekly 15 minute quiz on the previous week's material). All classes except for exams (95% of class time) were held in a computer lab. During class, students were given textbook-type and homework-type examples and control system projects to work on individually or in small groups. These projects paralleled the weekly homework and quiz topics. If students were unable to make progress on the projects, the professor would work with an individual group or engage the entire class in a discussion about how to solve the particular projects. Projects were often open-ended and required several class periods to complete. These projects were similar to the lab problems posed in the TC, but were more complex and required more time. Also, there were more of them in the IC than in the TC offering.

Results and Discussion

Group Similarity

We compared student performance in past courses to help identify any a priori differences between the IC and TC groups. All students had completed MEGR304 Instrumentation and Data Acquisition, which covers basic techniques used to collect and analyze data, and MEGR324 Heat Transfer, a traditional mechanical engineering heat transfer course covering convection, conduction and radiation. Students in both the IC and TC groups took both of these courses two quarters prior to taking the Control Systems course and were taught by those same instructors, with the same books, and in the same format. We also compared the average GPA for the IC and TC groups at the time of graduation, one quarter after taking control systems. The results are shown in Table 2. There are no statistical differences between the groups, suggesting that the IC and TC groups were very similar in background and ability.

The effectiveness of the IC was then evaluated by comparing content coverage, quiz and exam performance, and student perception of teaching, learning and of the inverted classroom format. Detailed analysis of the data comparing the 2010 TC and 2011 IC is presented in Mason, Shuman and Cook[28].

Table 2. Student Performance in Prior Courses and at Graduation

	TC 2010 (N=20)		*IC 2011 (N=20)*		*IC 2012 (N=22)*		*p value*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*2010 vs. 2011*	*2010 vs. 2012*
MEGR304	0.863	0.028	0.873	0.040	0.868	0.054	0.37	0.71
MEGR324	0.837	0.033	0.851	0.031	0.842	0.052	0.18	0.71
GPA	3.260	0.334	3.330	0.277	3.23	0.29	0.47	0.76

Content Coverage

Table 3 compares the material covered in the TC with that covered in the ICs. The table shows the first time the topic was assessed through a quiz or exam and thus the time by which students were expected to have learned the material. By the 4th week both IC classes were ahead of the TC. By the end of the quarter, the 2011 IC had covered Full State feedback design and Ackermann's formula, topics not covered in the TC class. The 2012 IC just covered the same material as the TC, but the 2012 class time was shortened by approximately one week due to heavy snow fall. In general, the IC format allowed the instructor to add approximately one week of extra content to the 10-week course.

Student Quiz and Exam Performance.

During all of the three course offerings, grades were recorded for every quiz and exam problem for every student. In the 2010 TC and 2011 IC offerings we compared student performance on pairs of similar quiz and exam problems. To ensure the problems used for this comparison were equivalent across offerings, the problems were matched independently by the course instructor, by a co-author, and by an adjunct faculty familiar with control systems. Analysis was done only on those problems that all agreed were good matches. Matched problems addressed identical course outcomes, had a similar question format, and were given at approximately the same time during the quarter. For a more detailed discussion see Mason, Shuman and Cook[28].

Table 3. Course Content Coverage

2009 TC Week	*2011 IC Week*	*2012 IC Week*	*Topic*
2	2	2	Ladder Logic
3	2	3	Signal Flow Graphs
3	3	3	Block Diagram
4	4	3	TF OL Analysis
4	4	4	Proportional Control
5/6	4	4	Root Locus
6/7	5	5/6	PID Design
8	6	7	OL Bode Plot Analysis
8	7	8	Bode Phase Lead Design
*	7	8	Bode Phase Lag Design
9	8	9	Nyquist Stability Analysis
10	9	10	Transfer Function to State Space (review from a previous course)
10	9	10	State Space Open Loop Analysis
10	9	10	Similarity Transformations
10	9	10	Controllability/Observability
*	10	*	Full State Feedback Design
*	10	*	Ackermann

* not covered

Twenty problem pairs were matched between the 2010 IC and 2011 TC offerings: 9 from quizzes, 5 from midterms, and 6 from final exams. An example of each type of problem pair is given in Table 4.

The problems were grouped with other problems covering the same topics or outcomes. Problems that involved design were also grouped. A brief description of the problem areas and their scores are shown in Table 5 (next page). It should be noted that all three state space analysis problems compared herein were more complex in the 2011 IC offering. For example, one matched problem asked students to analyze a controller for a plant given in state space form. In the TC that problem was 2nd order but in the IC it was 3rd order. Results for state space problems are included in the results but noted that the IC problems tended to be more difficult.

Table 4. Comparison of three problems from TC and IC offerings

2010 TC	*2011 IC*
Quiz Problem Draw the bode plot for the plant and estimate the gain and phase margins $G(s) = \frac{40(s+5)}{s^2 + 2(0.7)10s + 10^2}$	*Quiz Problem* Draw the bode plot for the plant and estimate the gain and phase margins $G(s) = \frac{40(s+3)}{s^2 + 2(0.7)15s + 15^2}$
Midterm Problem Design a proportional feedback controller for a plant modeled by the following transfer function $G(s) = \frac{s}{s^2 + 2s + 101}$ 1. Write the closed-loop characteristic equation 2. Draw a root locus plot for K (proportional feedback) 3. Write the desired closed-loop equation for the system with a damping ration of 0.7 4. Compute the value of the gain K so that the system has a damping ration of 0.7 5. Compute the approximate settling time for the closed-loop system	*Midterm Problem* Design a proportional feedback controller for a plant modeled by the following transfer function $G(s) = \frac{s}{s^2 + 5s + 49}$ 1. Write the closed-loop characteristic equation 2. Draw a root locus plot for K (proportional feedback) 3. Write the desired closed-loop equation for the system with a damping ration of 0.7 4. Compute the value of the gain K so that the system has a damping ration of 0.9 5. Compute the approximate settling time for the closed-loop system if K is adjusted so that the damping ratio is one
Final Problem Design a PID controller for the system $G(s) = \frac{10}{s+2}$ so that the closed-loop system has a settling time of 2 seconds, a damping ratio of 0.7 and no steady state error to a step input.	*Final Problem* Design a PID controller for the system $G(s) = \frac{10}{\frac{s}{4} + 1}$ so that the closed-loop system has a settling time of 1 second, a damped natural frequency of 5 r/s and no steady state error to a step input.

Table 5. Problem Groups by Topic

	Number of Problems			Problem score (normalized out of 10)		
Problem Area	*Quiz*	*Midterm*	*Final*	*TC 2010 Mean (SD)*	*IC 2011 Mean (SD)*	*p-value*
Create a ladder logic diagram for a simple discrete control problem	1			8.20 (2.21)	8.15 (2.01)	.941
Analyze the open loop properties of a system	2	3		8.34(.702)	9.09 (.711)	.002*
Sketch the root locus of a system when varying a specified parameter in the system		1	1	9.04 (.780)	9.30 (.70)	.277
Design a PID controller, using root locus method	2	1		7.79 (.964)	8.79 (.966)	.003*
Design a PID controller, by matching coefficients (algebraic design)			1	9.55 (.999)	9.25 (.851)	.313
Design a phase lead or phase lag control system, using bode plots	2		1	6.72 (.945)	8.25 (1.30)	< .001*
Evaluate the stability of a system using Nyquist diagrams	1		1	7.68 (1.41)	7.52 (1.94)	.770
Calculate open loop performance parameters, such as damping ratio, for a system in state space form	1		2	9.48 (.587)	8.6 (1.23)	.006*
Design (Root Locus Design, Algebraic[1] Design, Bode Based Design)	4	1	2	7.58 (.750)	8.61 (.980)	.001

[1] No exact match possible: problems were 2nd order in TC and 3rd order in IC
* Statistically significant results, $p < .003$

Results of the detailed performance analysis of the 2010 TC and 2011 IC group show that the IC group performed statistically better on problem sets involving Open-Loop Analysis, Root Locus based design, and Bode plot Based controller design. When all design problems (Root locus, Algebraic, and Bode Based) were aggregated together, the IC group performed statistically better than the TC group[28]. These results are somewhat deceiving because in all cases the aggregated results are dominated by a few problems. In the open loop analysis, for example, the IC group performed statistically better on only 2 of the 5 problems, while there was no statistical difference on the remaining 3.

Due to the differences in course structure we did not perform the same detailed comparison between the 2010 TC and 2012 IC. However, we did compare aggregate student scores for the entire term for all three offerings. Specifically, we compared student performance on the aggregate of the quiz and exam problems that covered a given course topic. This analysis is not as refined as the previous analysis; in some cases one problem may cover multiple topic areas.

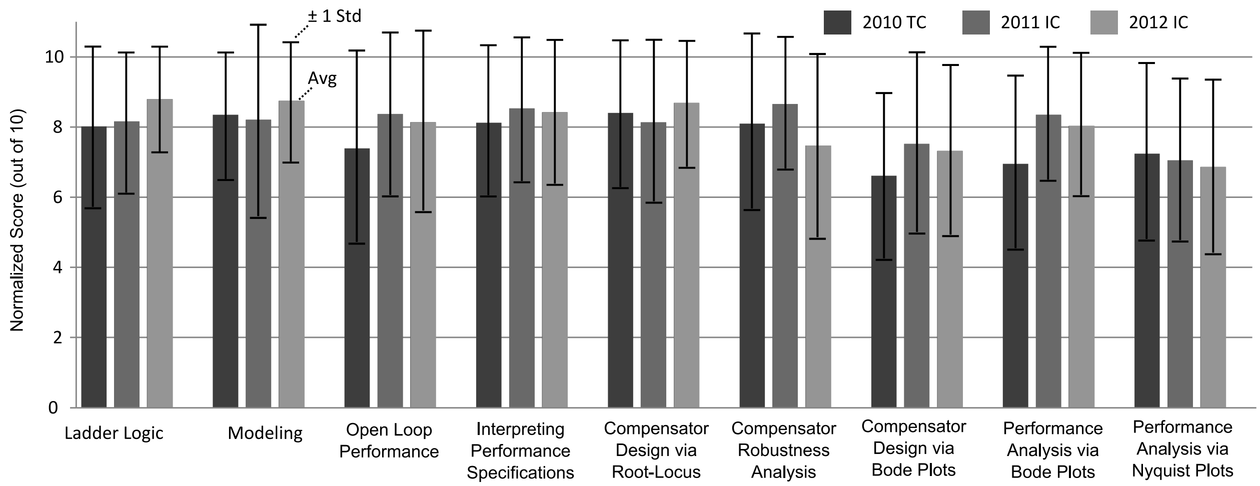

Figure 1. Comparison of Student Performance on Course Topics

Figure 1 shows the class average plus and minus one standard deviation for aggregate scores on quiz and exam problems related to specific topics. Inspection of Figure 1 reveals that the standard deviation bars overlap; no mean is greater than 1 SD from any other. A t-test comparing scores between pairs of years confirmed that scores aggregated by general topic area for any one year do not significantly differ from the scores of any other year ($p > .05$). This suggests that there is no difference in student performance on aggregated scores from test or exam problems.

In conclusion, the IC format at best improved student performance in some areas, specifically those involving design from 2010 to 2011, and at worst did no harm. This is significant because in both of the IC courses the instructor progressed faster through the material – covering more material in 2011, and the same material in less time in 2012, while at the same time freeing up class time for learner-centered activities.

<u>Student Perception of Teaching.</u>

At the end of every course, the department administers an anonymous student perception of teaching (SPOT) survey. The survey asks students to rate various aspects of the course on 5-point Likert scale. We compared these survey results from the IC and TC offerings. Results from the SPOT surveys are summarized in Table 6 (next page). Student satisfaction between the 2010 TC and 2011 IC was similar and overall slightly lower for the 2012 IC. The results, however, were statistically different in only three areas.

First, the 2012 IC felt the course organization and the use of time were worse than the TC group. These findings are interesting since the course structure was identical to the 2011 IC group and that group reported no problems with course structure. The 2012 IC group, however, did express more frustration with the lack of guidance on watching class videos. In addition, the 2012 class

Table 6. Results from SPOT survey for survey questions

Question	*2010 TC Mean (SD)*	*2011 IC Mean (SD)*	*2012 IC Mean (SD)*	*p- value*	
				2010 TC vs. 2011 IC	*2010 TC vs. 2012 IC*
The course as a whole was well-organized[1]	4.47 (.51)	4.45 (.69)	3.91(.75)	0.90	0.01*
The instructor's use of class time was effective. [1]	4.58 (.51)	4.35 (.81)	3.91 (.92)	0.30	0.01*
The instructor's attitude and teaching style encouraged my learning. [1]	4.37 (.76)	4.65 (.59)	4.05 (1.04)	0.21	0.28
My overall impression is that the instructor was an effective teacher. [1]	4.63 (.50)	4.75 (.44)	4.27 (.63)	0.44	0.06
The instructor appropriately assessed learned skills through exams or reports, etc. [1]	4.21 (.79)	4.65 (.49)	4.09 (.92)	0.05*	0.66
Over the entire term I spend approx. __ hrs studying for this course per week[2]	8 (1.34)	5.5 (1.42)	8.2 (1.92)	<0.01*	0.71

[1] Likert scale 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree
[2] Hours per week

*Statistically significant results, $p<0.05$

met three times a week whereas the 2010 and 2011 groups met four times a week. Another difference was that the 2012 class missed a week of class due to inclement weather. These factors may be reflected in the results.

Second, the 2011 IC reported that the instructor better assessed their learning through exams and quizzes. This is puzzling since exams and quizzes for all three offerings were very similar. Other results (see *Student Perceptions of the Inverted Classroom*) suggest that the 2011 IC students felt more comfortable with the material and this greater comfort may have made the assessments seem more apt.

Finally, the 2011 IC reported spending significantly less time studying for the course than the 2010 TC group while the 2012 IC reported spending the same amount of time. The 2011 IC finding contradicts the finding of other studies[14] that show students in an IC format study more. It stands to reason that students would spend more time outside of class in an IC since they are required to do homework and study for exams, just as in a TC, with the addition of watching videos. In our case it may be that the 2011 IC group did not perceive watching videos as "studying". While this seems to contradict the 2012 IC results, meeting fewer days per week and missing the week for weather may have made these students feel the need to study extra to compensate. Regardless, the results suggest than an IC does not require students to spend significantly more time studying than does a TC. This is a key result. It's worth noting that the instructor in both IC offerings reduced the grade weighting on homework to allow students more flexibility to use homework assignments as a study tool to help them learn material outside of class, thus relieving some of the workload due to homework.

In addition to multiple choice questions, discussed above, the SPOT surveys also asked three open-ended questions: 1) What aspects of the teaching or content of this course or laboratory section do you feel were especially helpful? 2) What changes could be made to improve the teaching or content of this course or laboratory section? 3) Additional Comments. Representative student comments are given in Table 7. In the TC offering, students liked computer lab demos and how course content related to real-world applications; 7 of the 14 comments that suggested improvement asked for more lab time. In the 2011 IC course, 14 of the 20, and in the 2012 IC, 12 of the 22 comments relating to what the students liked in class pointed to the usefulness of the online videos. In the 2011 IC course, 10 of the 20, and in the 2012 IC 7 of the 22 comments stated that in-class projects contributed to their understanding of the concepts.

Table 7. Representative student comments from SPOT forms

2010 TC	*2011 IC*	*2012 IC*
What's Good	*What's Good*	*What's Good*
Demonstrations in the computer lab. Practice quizzes were nice too	I liked the new method of teaching. I felt that it forced me to spend time outside of class to actually learn the material	The quizzes are helpful to know what [I] need to study for this class
The real world applications. The mini labs/demos. Weekly quizzes are great	Since the lectures are on YouTube, we have more time to focus on examples. This way also kind of forces student to study before class first; otherwise it is hard to follow what the instructor did in the class example	The videos were great! It was nice to be able to go back and re-listen to lectures.
Quizzes each week keep you on top of the material; fair tests	I liked having the videos as an additional tool to learn. The videos were helpful because I was able to pause at any moment to take notes, or rewind if I missed something. I liked doing examples in class. I was able to learn more	The learning style was good. It took over half the quarter to finally get used to it. I recommend starting this learning style in a different class.
Needs improvement	*Needs improvement*	*Needs improvement*
If there was a lab accompanying this course it would help significantly to see how the theory gets implemented to an actual system that needs to be controlled	With new structure of class, stagger homework. i.e., HW 1 prob 1 due Mon then discuss, HW 1 prob 2 due Tues then discuss. This will help the class to stay on target with new class idea	More organization with videos (only watched 5 out of the many videos for the quarter)
More labs, self design lab - final project	The videos did not always have important details that were necessary to solve quiz problems, this made studying for the quizzes difficult at times	Better way of knowing which videos to watch and when.

While students valued the online videos, in the 2012 IC course, 4 of the 17 and in the 2012 IC course 5 of the 19 comments asked for a more structured course organization. In the 2012 IC course four of these five suggestions indicated frustration with not knowing which video to watch. One difference between the two IC courses was that the videos in the 2011 IC were created and posted one to two weeks before the material was covered in the course. In the 2012 IC, all videos were available at the start of the course. Thus students in the 2012 IC course were expected to identify relevant videos on their own. The instructor structured the course intentionally this way in 2012 to help promote independent learning. Eventually the instructor did post a suggested viewing list for students in response to students' frustration.

Student Perceptions of the Inverted Classroom

Student perceptions of learning in the IC format were assessed in the 2011 IC and the 2012 IC courses at the 4th and 10th week of the quarter through an anonymous survey. The survey contained 15 questions with 5-point Likert scales and space for open-ended "additional comments". Later, results from the 4th and 10th week survey were paired for each student. Following the surveys, students participated in an in-class discussion facilitated by a faculty member not teaching the course. Results of the survey and discussion are separated into three sections and summarized below.

Perceived Effectiveness of IC classroom. Results from the survey used to measure student perception are shown in Tables 8 and 9 (next page) for the 2011 IC and 2012 IC courses. Results suggest that students in both IC courses perceived that they were learning more in this course than in their other engineering courses (taught in TC format). Since there is no significant difference between the 4th and the 10th weeks it appears that this perception was developed before the 4th week of the quarter. Moreover, by the tenth week students from both IC offerings rated their IC course as better than their traditional courses. However the 2012 IC liked the course format statistically less than did the 2011 IC. Overall the 2012 IC students rated the course lower in every category than did their 2011 counterparts. This may be due to three factors: 1) the unusual and prolonged snow closure that distracted from the systematic development of course material, 2) the fewer, yet longer class meetings resulting in more massed than distributed practice, and 3) the 2012 students' initial struggle with which lectures to watch. We surmise that this last factor led students to feel that although they were learning a lot, they did not know if they were learning the right things, thus fearing for their grades and increasing their dissatisfaction with the course. This supposition can be supported by the representative written comments provided in Table 9.

Table 9 shows comments made by the same student in week 4 and 10, a total of three students in 2011 and two in 2012 offerings. Students in both years recognized that the new format required self-discipline and necessitated some adjustment to their study habits, but that the IC format provided a better learning experience once the adjustment was made. In general, students also felt that the IC resulted in a better use of class time and that this format better prepared them for engineering practice.

Table 8. Perceived effectiveness in the 4th and 10th weeks for the 2011 and 2012 IC offerings

	2011 IC[1]		*2012 IC*[1]		*2012 IC vs. 2011 IC at 10th week*
Question	*4th week Mean (SD)*	*10th Week Mean (SD)*	*4th week Mean (SD)*	*10th Week Mean (SD)*	*p value*
How much to you feel you are learning? (1= too little, 3=similar to other courses, 5 =too much)	3.76 (.66)	4.12 (.78)	3.48 (.88)	3.66 (.75)	0.065
How do you like the class format: no lectures, all example problems? (1=not at all, 3=typical, 5=I like it a lot)	3.71 (.98)	4.09 (.83)	2.86 (1.13)	3.10 (1.42)	0.015*
Compare this class format to traditional, lecture style format? (1=this format is much worse, 3=similar, 5=much better)	3.53 (.80)	3.82 (.64)	2.98 (1.2)	3.25(1.33)	0.072
Compare this class format to traditional, lecture style format in terms of your learning? (1=much worse, 3=similar, 5=much better)	3.47 (.87)	3.68 (.81)	2.76(1.23)	3.32(1.10)	0.16

[1] there was no statistically significant change ($p<0.05$) from 4th to 10th week in either offering

*Statistically significant results, $p<0.05$

Table 9a. Perceived effectiveness – representative 2011 IC student written comments

Week	*Matched Student Comments in 2011 IC offering*
4th week	There is a lot to learn I just haven't been able to grasp it yet. Examples are very useful but a lot of time I don't know what is going on. I am not used to the class format yet. Videos are good for very basic explanation.
10th week	This class format has taken time to get used to but once you do it works; I think this format is good for some classes but not for others. You need one that does not have ton of theory, something like thermodynamics. I think it would work for dynamic systems.
4th week	I very much enjoy this format. Many students do not because they want to wait until the last minute to start the homework. I feel this best prepares us for how we will solve problems in our jobs.
10th week	Need more class time to do examples, not that there isn't enough, just that the class period needs to be longer.
4th week	The structure of the class was uncomfortable at first but I feel that I learn faster when I am responsible for learning class material.
10th week	Class time is more efficiently used

Table 9b. Perceived effectiveness – representative 2012 IC student written comments

Week	*Matched Student Comments*
4th week	I prefer in-class lectures to video lectures because the professor is allowed to expand on the basic lecture material. They explain things different ways, use real-engineering examples, and perceive the current understanding of the class. If one of the class periods per week was devoted to lecture summary then time with in-class examples wouldn't be wasted catching up the class.
10th week	I like the videos a lot but I think he should still lecture or summarize the videos before doing examples. I also think he should do harder examples in the videos.
4th week	After this class I will know a lot but my grade will not show this. I learn a lot but don't know if I am learning the right info. And the right info is not explained until after the quiz. Don't feel the HW aids in preparing for the quiz.
10th week	The material is relatively straightforward but the additional change in learning style made it harder. After about half the quarter it started to get easier. Once you figure it out I think it is better for learning but more time consuming. Should be implemented before senior year.

Table 10. Contributions to learning

	2011 IC[1]		*2012 IC*[1]		*2012 IC vs 2011 IC at 10^{th} week*
Question	*4th week Mean (SD)*	*10^{th} Week Mean (SD)*	*4th week Mean (SD)*	*10^{th} Week Mean (SD)*	*p value*
How do professor's videos contribute to your learning? (1=not at all, 3=typical, 5=very useful)	3.94 (1.14)	4.18 (.73)	3.68(1.25)	4.02 (1.10)	0.409
How many times, on average, do you watch each video?	2.41 (1.00)	2.88 (.99)	2.99 (1.33)	3.05 (1.58)	0.804
How does the in class time contribute to your learning?(1 = not at all, 3=typical, 5=very useful)	3.41 (1.23)	4.24 (.75) [1]	3.61 (1.11)	3.48 (1.14)	0.057

[1] change from 4^{th} to 10^{th} week is statistically significant, $p<0.05$

Factors that contributed to student learning. A summary of students perception of how the videos and class-time contributed to their learning are summarized in Table 10. The students' perception of how videos contributed to learning didn't change between the 4^{th} and the 10^{th} week of the quarter. The 2011 IC showed an increase in the effectiveness of class time whereas the 2012 IC showed a decrease (although not statistically significant). Students reported that they re-watched videos more often later in the quarter in both offerings. In their written comments the 2011 IC students stated the videos were a key contributor to their learning. During in-class discussion, students from both offerings voiced that they liked being able to re-watch the videos.

During the class discussions on the 4^{th} week of the course, students expressed some frustration with the IC, but were learning to adjust. This level of frustration was much higher in the 2012 IC than in the 2011 IC. The majority of those in the 2011 IC liked the IC format because it forced them to study the material ahead of class in order to be able to follow what is going on during class.

During the class discussion on the 10^{th} week of the quarter, one 2011 IC student openly expressed that he did not like this format because it was too easy to put off the work. By this time in the quarter the instructor had begun presenting a 10-minute lecture at the start of the class to clarify concepts needed for the day. This change was done to address frustration students were experiencing with the open ended learning style of the IC. All students were appreciative of theses mini-lectures. All students agreed that Control Systems should continue to be taught in the IC format.

Appropriateness of the IC to other classes. Students commented that the IC format may not work in a course with many new concepts, such as a heat transfer, because students would struggle identifying where to apply the various new concepts and equations. However, students may have underestimated the number of new concepts tackled in Control Systems. Students were asked to speculate on how well the IC would work in other classes. Their responses collected through the survey show that thirty-one percent (2011 IC) and 18% (2012 IC) felt the IC was appropriate to only senior classes, 32% (2011 IC) and 42% (2012 IC) for junior and senior classes and 37% (2011 IC) and 13% (2012 IC) sophomore, junior and senior classes. Only one student thought it would work in a freshman setting (2012 IC).

Instructor Observations

The instructor had several observations about the two formats. He had taught the course 12 times using the TC format. One persistent frustration was that the TC did not give students an opportunity to apply their knowledge. The IC allowed more time to do in-class design projects. It also gave the instructor the freedom to take class time to answer questions without the pressure of losing the time needed to cover course content. At the end of the course, one student spontaneously commented that he particularly liked the course format because he felt he could now actually design a controller for a real system.

One unexpected observation was that students who normally excelled in lecture classes initially seemed the least comfortable in the IC class. This was particularly true of the 2011 IC offering. Several students commented to the instructor that they had a pattern of listening to the lectures before reading the text or working on the homework. This pattern did not work in an IC class. In contrast, students who tended to perform poorly in lecture classes seemed to adapt to the IC format quickly. Several students commented that it was easier for them to learn the material because they could watch the lectures at their own pace and re-watch sections that they didn't understand. One student in particular visited the instructor's office several times and commented that if he had been taught this way all along he would had done better in other courses.

Finally, an IC requires a fair amount of time to implement the first offering. For this course the instructor produced 50 videos; 45 were developed in 2011 and 5 were added in 2012. Recording a 10 minute video took 30-60 minutes. The approach was to first create a script for the video.

The script looked similar to notes for a short lecture. These notes were then handwritten on a Tablet PC using Window Journal. Simultaneously, verbal commentary was recorded using an external microphone. These were captured in real time using Camtasia[30] screen capture software. The recording only showed the PC screen with the notes appearing as the instructor discussed the topic. When recording, the instructor kept the "tape rolling"; errant sections were removed during editing. A typical draft video would be 15 – 25 minutes long. During editing, verbal pauses were removed and segments with writing but no meaningful voice-over were shortened. After editing the final video was typically 5-10 minutes long. Editing such a video took up to one hour. The instructor estimates the total time to produce the 45 videos in the 2011 IC was around 80 hours. In a 10-week quarter this equates to dedicating one full day a week to create content for the course. Fortunately this effort need only be done the first offering. Once the videos are prepared, however, the instructor felt that class preparation for the IC took less time than for the TC.

Lessons Learned

The IC format proved to be a successful means to free class time for active learning and problem solving activities. There are several lessons to be learned from this study:

1. An IC can allow the instructor to cover more material than in a TC. This seems logical since students are expected to watch lectures outside of class. The unexpected result is that this format does not have to require more time outside of class for students, provided the instructor makes appropriate adjustments to homework load.

2. An IC format does not compromise student learning on fundamental topics. In our study students in the IC performed equal or better than TC students on traditional quiz and exam questions. This study did not evaluate the effect on student's problem solving abilities, but students in the IC did have substantially more practice solving open-ended problems. Both the students and the authors believe this can only better prepare them for their engineering career. Future research will examine how students perform on real-world problems. An NSF TUES grant proposal submitted in 2012 may allow the authors to do just that.

3. Based on lesson 1 and 2 above, it follows that an IC is a valid structure for freeing class time so it can be devoted to learner-centered activities such as problem-based learning.

4. As with anything new there is some resistance. We experienced more resistance in the 2012 IC than in the 2011 IC, so resistance may depend on the class makeup and how the course was structured. For example, in the beginning of the 2012 offering, students did not receive any guidance on which videos to watch and when, whereas 2011 group did receive guidance by having lectures posted proximally to their "use" date. In general though, most students adapted quickly to the new format. It's important for the instructor to establish expectations early in the class. Students who do not come to class prepared will be frustrated and unable to benefit from the in class activities. While we did not use daily quizzes, other researchers[11,22] recommend a pre-quiz to ensure students come to class prepared.

5. An IC takes time to develop. The authors don't recommend implementing an IC in the first offering of a class. It takes experience with the material to know how to break it into small enough segments for useful videos. With careful planning it may be possible to implement an IC in phases – covering only parts of the course using an IC format. The potential problem is that students take time to adapt to an IC. If the IC segments in a course are too short students may be frustrated and not have time to adapt to the new learning format.

6. While course material for an IC requires a substantial investment in time, IC videos don't have to be production quality. The key is that they are accessible (e.g. youtube) and short (no longer than 15 minutes) to keep student's attention throughout. Substandard videos can be redone at a later time.

7. Instructors don't have to develop a complete set of problem-based learning problems before implementing an IC. They can use class time to involve students in simple learner-centered activities using the lecture examples or textbook-type problems they used when teaching the class in a TC format. The key is to give students an opportunity to apply their knowledge, identify misconceptions, and have an opportunity to correct those misconceptions with the help of the instructor.

8. A successful IC must provide students with adequate structure. The authors recommend providing students with a suggested video viewing list per topic and if necessary giving a 5-10 minute mini-lecture to clarify the fundamental concepts being applied during that day's activities.

Our experience shows that the IC format can free class time for learner-centered activities without sacrificing course content or student performance on traditional quiz and exam problems. The IC encourages students to become self-learners, and we contend, better prepares them for how they will need to learn as practicing engineers.

References

1. Jamieson, L.H. and Lohmann, J.R.(2009), (Eds.) Creating a Culture for Scholarly and Systematic Innovation in Engineering Education: Ensuring U.S. engineering has the right people with the right talent for a global society, American Society for Engineering Education: Washington, D.C.
2. NAE (2005), Educating the Engineer of 2020: Adapting Engineering Education to the New Century. 2005, National Academic of Engineering: Washington, D.C.
3. Felder, R.M. and Brent, R. (2004), *The Intellectual Development of Science and Engineering Students. I. Models and Challenges*, J. of Eng. Educ., **93**(4): p. 269–277.
4. Prince, M. and Felder, R. (2006), Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. J. of Eng. Educ., **95**(2): p. 123-138.
5. Litzinger, T.A., Lattuca, L R.., Hadgraft, R. G., and Newsletter, W. C. (2011), *Engineering Education and the Development of Expertise*, J. of Eng. Educ., **100**(1): p. 123-150.
6. Prince, M. (2004) , *Does Active Learning Work? A Review of the Research.* J. of Eng. Educ. **93**(3): p. 223-231.

7. Terenzini, P. T., Cabrera, A. F., Colbeck, C. L., Parente, J. M., & Bjorklund, S. A. (2001) *Collaborative learning vs. lecture/discussion: Students' reported learning gains*. J. of Eng. Educ, **90**(1): p. 123-130.

8. Felder, R.M., Felder, G.N., and Dietz, E.J. (2002),*The Effects of Personalty Type on Engineering Students Performance and Attitudes*, J. of Eng. Educ., **91**(1): p. 3-17.

9. Yadav, A., Subedi, D., Lundeberg, M.A., and Bunting, C.F. (2011), *Problem-based Learning in Electrical Engineering*, J. of Eng. Educ., **100**(2): p. 253-280.

10. Matthew, R. G. S., & Hughes, D. C. (1994) *Getting at deep learning: A problem-based approach*. Eng. Sci. Edu. J., **3**(5): p. 234–240.

11. Zappe, S., Leicht, R., Messner, J., Litzinger, T., and Woo Lee, H. (2009) *"Flipping" the Classroom to Explore Active Learning in a Large Undergraduate Course*. in Proceedings of 2009 ASEE Conference, Austin, TX.

12. Dollar, A., (2011) ASEE Annual Conference 2011, Main Plenary, URL: http://www.it.uu.se/research/group/upcerg_new/events/ASEE2011_resources/plenary_slides.pdf, accessed on May 3, 2012.

13. Gannod, G., Burge, J., Helmick, M., (2008) Using the Inverted Classroom to teach Software Engineering, ICSE, May 2008, Leipzig, Germany, pp 777-786

14. Papadopoulos, C. and Roman, S.A. (2010), *Implementing and Inverted Classroom Model in Engineering Statics: Intial Results,* in Proceedings of the 2010 ASEE Annual Conference 2010. AC2010-1868.

15. Shell, A. (2002) The Thayer Method of Instruction at the United States Military Academy: A Modest History and a Modern Personal Account, Primus: Problems, Resources, and Issues in Mathematics Undergraduate Studies, 12:1, 27-38

16. Mazur, E., (2009) “Farewell Lecture?”, Science, 323, pp. 50-51.

17. Mazur, E., (2001) “Peer Instruction: Ten years of experience and results,” Am. J. Phys. 69 (9), September 2001, 970-977.

18. Lage, M., Platt, G., and Treglia, M. (2000) , Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment. J. of Econ. Educ., **31**(1): p. 30-43.

19. Bryan Goodwin, B. and Miller, K. (2013) “Evidence on Flipped Classrooms Is Still Coming In,” Educational Leadership, ADSC, March, pp. 87-80.

20. Flipped Learning Network (2013), http://flippedclassroom.org, accessed December, 2012.

21. Bland, L. (2006), Apply Flip/Inverted Classroom Model in Electrical Engineering to Establish Life-long Learning, in Proceedings of the ASEE Annual Conference 2006. Chicago, IL.

22. Day, J. and Foley, D.(2006), Evaluating a Web lecture Intervention in a Human-Computer Interaction Courses, IEEE Trans. on Education, **44**(4): p. 420-431.

23. Demetry, C. (2010), Work in Progress – An Innovation Merging “Clasroom Flip” and Team-Based Learning”, 40th ASEE/IEEE Frontiers in Education Conference, T1E-1.

24. Haden, C, Flikkema, P., Weller, T., Frolik, J., Verrel-Berenback, W., and Shiroma, W., The Assessment of a Hybrid On-Line/In-Class Course Developed at Multiple Universities, in Proceedings of 2009 ASEE Conference. 2009. Austin, TX.

25. Toto, R. and Nguyen, H. (2009), *Flipping the Work Design in and Industrial Engineering Course, 39th ASEE/IEEE* Frontiers in Education Conference, Session T4F, San Antonio, TX.

26. Kellogg, S. (2009) Developing Online Materials to Facilitate and Inverted Classroom Approach, ASEE/IEEE Frontiers in Education Conference, Session T3F, San Antonio, TX.

27. Rais-Rohani, M., Walters, A., and Vizzini, A. (2010), *Emporium Based Redesign of Statics: An Innovative Approach to Enhance Learning and Reduce Costs*. ASEE Annual Conference and Exposition. 2010. Louisville, KY.

28. Mason, G., Shuman, T and Cook, K. (2013), “Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in and Upper Divison Engineering Course”, accepted to IEEE Transactions on Education, 2013

29. Quanser (2012), http:www.quanser.com, accessed May 2012

30. Camtasia (2012), http://www.techsmith.com, accessed May 2012

31. Stief, P. and Dollar, A., (2009) “Web-based Statics Course: Study of Usage Patterns and Learning Gains,” J. of Eng. Educ., **98**(4): p. 321-333.