AC 2010-1868: IMPLEMENTING AN INVERTED CLASSROOM MODEL IN ENGINEERING STATICS: INITIAL RESULTS

Christopher Papadopoulos, University of Puerto Rico, Mayagüez

Christopher Papadopoulos is a faculty member in the Department of General Engineerng at the University of Puerto Rico, Mayagüez, where he coordinates the Engineering Mechanics Committee. His research interests include nonlinear structural mechanics, biomechanics, engineering education, and engineering ethics, and he serves as secretary of the ASEE Mechanics Division. He holds BS degrees in Civil Engineering and Mathematics from Carnegie Mellon University, and a PhD in Theoretical and Applied Mechanics, Cornell University. He was previously a faculty member in the Department of Civil Engineering & Mechanics at the University of Wisconsin-Milwaukee.

Aidsa Santiago Roman, University of Puerto Rico, Mayagüez

Aidsa I. Santiago Román is an Assistant Professor in the Department of Engineering Science and Materials and the Director of the Strategic Engineering Education Development (SEED) Office at the University of Puerto Rico, Mayaguez Campus (UPRM). Dr. Santiago earned a BA (1996) and MS (2000) in Industrial Engineering from UPRM, and Ph.D. (2009) in Engineering Education from Purdue University. Her primary research interest is investigating students' understanding of difficult concepts in engineering science with underrepresented populations. She also teaches introductory engineering courses such as Problem Solving and Computer Programming, Statics, and Mechanics.

Implementing an Inverted Classroom Model in Engineering Statics: Initial Results

1. Introduction

The "Inverted Classroom" is described by Lage et al. as an environment in which "events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa"[1]. Typically, Inverted instruction requires students to complete preparatory activities and exercises prior to Lecture, usually online. This pre-lecture activity exposes students to new material and allows them to form initial conceptions, attempt problems, receive feedback, and formulate questions. By leveraging these outcomes, lectures can be less about direct dissemination of material and more about critical discussion and engaged learning activities.

Recent advances in educational software and internet-based instruction have been exploited to develop Inverted Classrooms, including in engineering education[2,3,4]. In 2009, Dollár & Steif[2] presented an Inverted Classroom model for Engineering Statics, delivered via the Open Learning Initiative (OLI)[5]. Inspired by this work, one of the authors designed and implemented an Inverted model for his sections of Statics at the University of Puerto Rico, Mayagüez (UPRM) for Fall 2009. Excited by positive student feedback and his own impressions of its effectiveness, he continues to use the Inverted method in Statics (Spring 2010), and has also implemented an Inverted model to deliver a 75-minute seminar in Engineering Ethics to UPRM freshman (Fall 2009, Spring 2010)[6].

To implement the new Inverted classroom for Statics, a set of customized Modules was newly created and delivered via the Moodle online courseware environment[7,8]. Prior to each Lecture, students must read one or two Modules (which consist of PowerPoint slide presentations) and complete corresponding Exercises. To promote engagement, the Modules use animation within each slide to allow students to process information dynamically, incrementally, and logically, and the corresponding Exercises are graded and provide feedback. We extended the idea of the Inverted Classroom to include a Problem-Solving Session following each Lecture, which is a regular, structured session in which students initiate homework exercises with the assistance of the instructor, teaching assistant (TA), and other students. The Problem Solving Session inverts the burden of initiating help-seeking from the student to the instructor, and inverts the setting for doing homework from outside to inside the classroom environment.

The primary assessment data is derived from a detailed student survey given at the end of Fall 2009. Survey results indicate strong student preference for the "Inverted" model compared to "Standard" lecture-style courses. In addition, we administered the Concept Assessment Tool for Statics (CATS)[9] in both the author's "Inverted" sections and other "Standard" sections of Statics. The average post-test score from the Inverted cohort exceeded that of the Standard cohort, although differing measures offer differing assessments of whether this difference is significant. Because our students are 100% Hispanic, and most speak English as their second language (Spanish being their primary language), our results suggest that the Inverted method has potential to be effective across

cultural and demographic boundaries (in addition, our results provide the first CATS data derived from a homogeneous population of Hispanic, bilingual students). However, the average post-test score of even the Inverted cohort was at the low end of the range of post-test scores reported from other U.S. institutions. It is not yet clear whether language or other cultural issues influenced these results.

2. Overview and Pedagogical Underpinnings of the Inverted Classroom Model

2.1 Overview. In Fall 2009, one of the authors (C. Papadopoulos, henceforth referred to as the "Instructor") taught two of twelve sections of Statics offered at UPRM. Inspired by Dollár & Steif's[2] presentation at the 2009 ASEE Conference, he designed and implemented a new Inverted Classroom with the following three basic components:

1. **Pre-Lecture Modules**, consisting of PowerPoint slides accompanied by **Exercises** (usually online and graded), delivered via Moodle and completed prior to Lecture;
2. **Lecture,** consisting of focused discussion and activities leveraging the prior exposure gained in the pre-lecture Modules and Exercises;
3. **Post-Lecture Problem-Solving Session** after each Lecture (twice per week), encouraging students to initiate homework and related help-seeking activities.

The relation between the Modules (component 1) and the Lecture (component 2) constitutes Inverted instruction in the usual sense. That is, relying on the students' exposure to new material and activities prior to Lecture, the amount of "pure lecturing" during class time is reduced and more time is devoted for critical discussion, problem-solving activities, and addressing student questions.

The relation between Lecture (Component 2) and Problem-Solving Session (Component 3) represents our extension of the inverted structure. Whereas the responsibility of initiating help-seeking is traditionally placed on the student (e.g., whether to go to office hours), here we provide and promote a standard time for students to begin homework and seek help. To encourage participation, the Instructor created customized homework assignments for which no prepared answers exist in a solution manual, and awarded up to 3% of the student's final grade based on weekly attendance of the Problem Session.

We are impressed with the Statics modules developed by Dollár & Steif[2] and delivered via the Online Learning Initiative (OLI)[5], and the Instructor carefully considered how to use them for Fall 2009. However, for a variety of reasons both philosophical (e.g., treatment of sign conventions) and logistical (e.g. limited enforced grading of exercises on OLI), he elected to create his own Modules, though a few selected OLI Modules were also required (e.g, the module regarding interactions of bodies). Based on our observations and the results of the survey at the end of the semester, students had a lower level of compliance with the OLI modules than with the Instructor's, and expressed a mixture of positive and negative feelings about the length and complexity of the OLI modules. Students generally indicated that they preferred to use either OLI or the Instructor's Modules, but not both (too much effort to use two systems). In 2010 the Instructor is using only his Modules and has not asked students to register for OLI.

2.2 Pedagogical Underpinnings. Educational literature from the last three decades indicates that various forms of active or engaged learning activities, meaningful and prompt feedback, and increased quality time-on-task are all important to student learning. All of these findings directly bear on the design and effectiveness of the Inverted Classroom. While we do not attempt a comprehensive review of this literature here, we cite and discuss selected works that have influenced our thinking.

A large body of research evidence suggests that active learning techniques – broadly taken here to mean any form of instruction that engages students beyond passively receiving information – promote learning[10,11]. A particularly convincing study conducted by Hake in the 1990's demonstrated that physics students exposed to some form of "interactive engagement" developed higher levels of conceptual understanding than those in "traditional" instructional settings[12]. Active learning grounds the SCALE-UP project at North Carolina State University[13], many of the integrated engineering curricula that emerged in the 1990's[14], and some of the emerging Inverted classrooms in engineering[2,3].

The relation of active learning to the Inverted Classroom model presented here is at least twofold. First, because some instruction is delivered prior to Lecture, less lecture time is needed to directly cover material, and more time is available for activities and exercises. The Instructor routinely provides between 15 and 30 minutes of each 75 minute Lecture for student problem-solving activities, and much of the remaining time is spent discussing and completing the problems with the entire class. Secondly, during the Problem-Solving Sessions (and to a lesser extent during the Lectures), students typically self-organize into small groups of 2-5 students each and work on problems together.

Complementing active learning is the provision of meaningful and real time or rapid feedback. Indeed, recent studies have demonstrated the effectiveness of leveraging learning technologies to provide real time feedback[15,16,17]. Dollár & Steif[2] provide a rationale for Inverted instruction based on a coupled system of synchronous student and instructor feedback loops (adapted from work of psychologist Marsha Lovett).

In our case, the pre-lecture online Exercises that accompany the Modules provide immediate feedback by allowing multiple attempts with hints to allow students to reach the correct answer. Lecture activities give students an opportunity to attempt problems independently before the Instructor presents the general solution, allowing students to confirm or revise their original thinking immediately based on the actual answer (see Section 5.3). Students also receive rapid feedback from the Instructor and TA during the Problem-Solving Sessions as they attempt the homework problems. In parallel to these student feedback cycles, the Instructor tunes the focus of Lecture activities to respond to observed patterns of student performance on the pre-lecture Exercises (results are recorded on Moodle and reviewed by the Instructor prior to class) and student questions that are raised either in response to the Modules or other in-class activities.

Finally, the need for students to spend sufficient quality time engaged in the learning task is a well accepted prerequisite for learning[18]. We observe that our students devote more time to this Inverted course than for other traditional courses (see Section 5.1), and based

on interactions with students, this time appears to be of good quality (i.e. they spend time trying to learn how to solve problems, not simply on rote memorization).

3. Detailed Descriptions of Classroom Components

3.1 Modules. Typically one or two Modules correspond to each 75-minute Lecture (i.e., 2-4 Modules per week). Collectively, the Modules introduce all of the fundamental theory of a standard course in Statics. The course material is redundantly scaffolded by a primary textbook[19] (i.e., each course topic corresponds to both a Module and section from the textbook). Although the Instructor emphasizes the Modules more strongly than the textbook, several examples and homework problems are borrowed from the textbook. However, to prevent students from copying answers from the publisher's solution manual, problems from the text are modified, and additional problems are drawn from a supplemental textbook[20] not identified to the students.

Each Module typically contains 10-15 slides and requires 10-20 minutes to read. Most Modules are accompanied by Exercises, usually completed online, but occasionally completed on paper and presented in class. All Modules and accompanying Exercises are posted on the Instructor's Moodle site at least 48 hours prior to the Lecture (the reader is invited to access the site as guest, as described in the Bibliography[8]).

The Instructor was cautious in using Power Point slides, feeling that if not properly designed or delivered, they lend themselves to passive teaching and learning habits. To promote critical and active thinking, the Modules use customized animation to strategically parcel and display information. Thus, at each slide, rather than seeing all of the information at once, students repeatedly press the "forward" button to see the information unfold (or the "back" button to repeat how the information was developed). In this way students better experience the logical development of the content. Devices such as highlights, pop-up questions & comments, animated graphics, and occasional voice clips are used to create visual and aural impressions to emphasize important points and insights. Figure 1 illustrates the Module on Two Force Bodies.

The Exercises that accompany the Modules are designed to be interactive, provide feedback, and to require about 5-10 minutes each. Exercises are usually online, multiple-choice, and are automatically scored. Moodle allows questions to be attempted multiple times by students, with incorrect answers generating feedback or hints customized by the Instructor. In some cases, however, Exercises require drawing or other demonstrative work; these are completed on paper and presented at the beginning of class (the TA checks these one at a time while the Instructor begins the Lecture). Figure 2 illustrates the Exercise accompanying the Modules on Two Force Bodies and Three Force Bodies (these Modules are delivered consecutively and simultaneously, so that students can use comparative reasoning to identify two vs. three force bodies). We are still learning how to optimally design questions and corresponding feedback in Moodle, and are looking for additional interactive tools that allow expository responses, such as the recently developed ARCHIMEDES that "allows the student to draw freebody diagrams and write free-form equilibrium equation in the same way as they would with paper and pencil",

and which "[a]t key times … assesses the student's work and gives immediate feedback on the correctness, completeness, and consistency of his/her solution"[15].

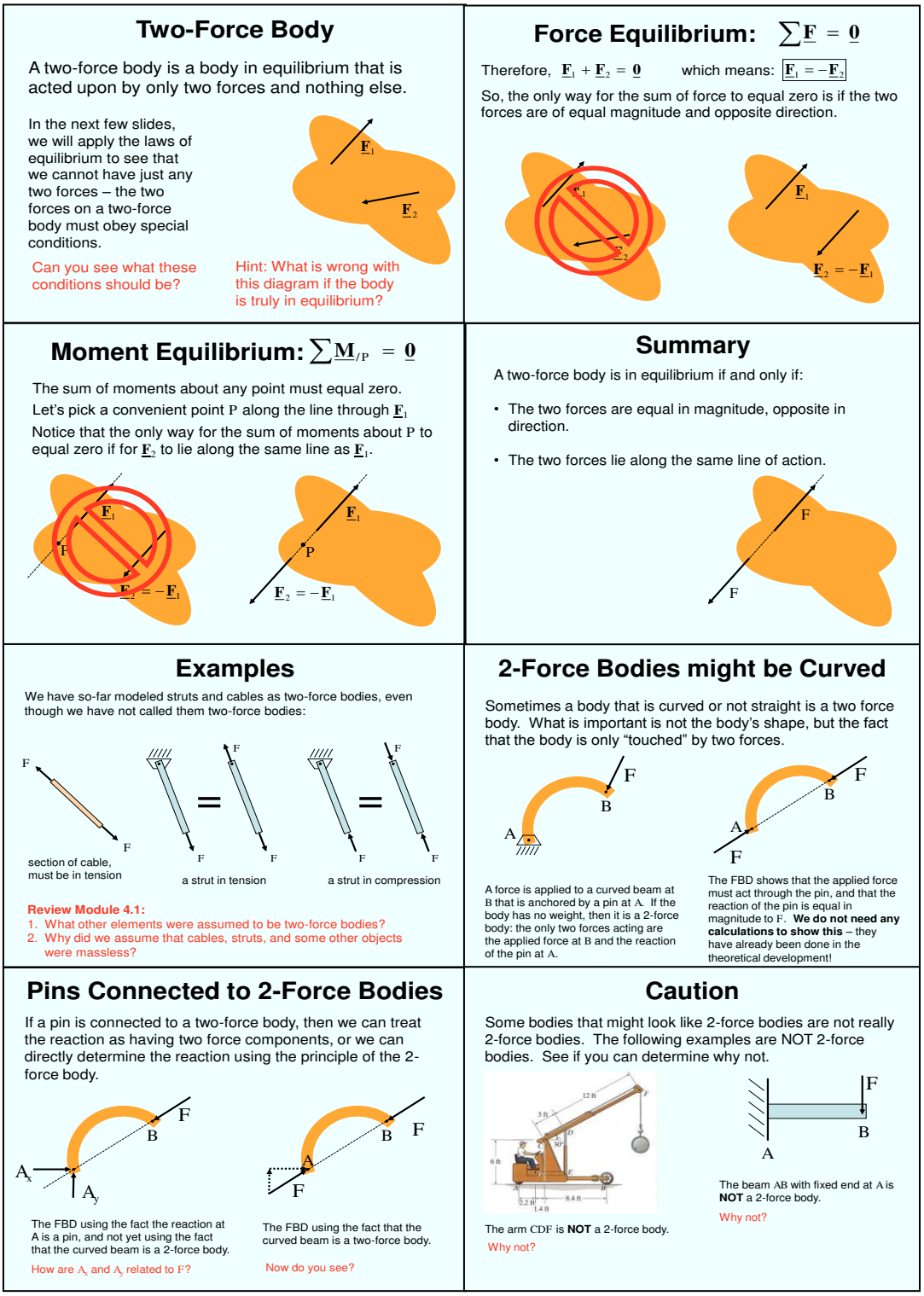

Figure 1. PowerPoint Slides Corresponding to the Module on Two Force Bodies (read from left to right, then top to bottom). Figures and text in red do not immediately appear until prompted by the "→" key.

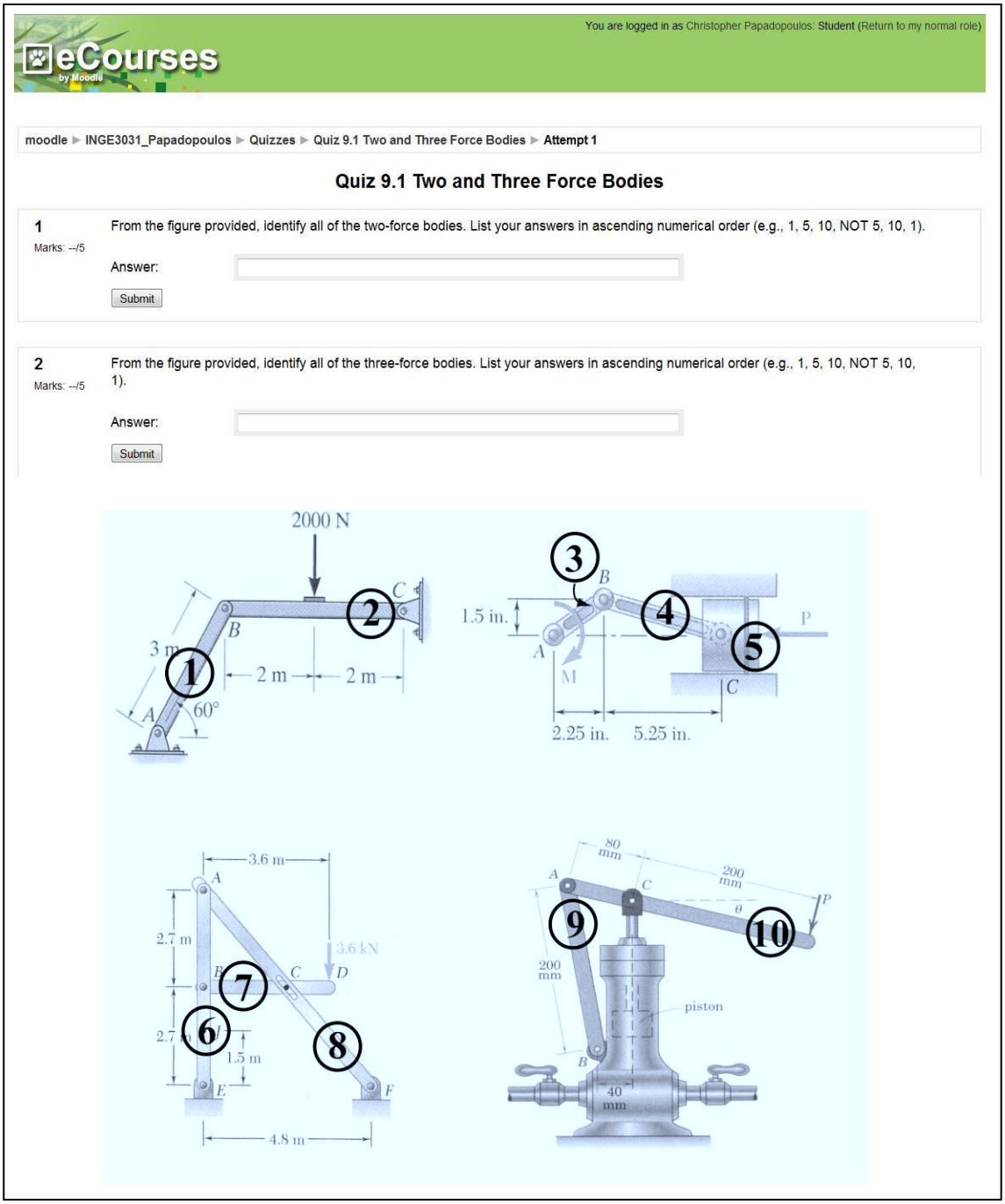

Figure 2. Online Exercise corresponding to Module on Two Force Bodies (edited and reformatted for printing here). Multiple attempts with hints are permitted, though with modest penalties for each attempt.

3.2 Lectures. In general, the Instructor begins each Lecture by projecting the corresponding Module (PowerPoint slides and/or Moodle pages) onto the screen at the front of the room. During the first two weeks of the semester, the Modules are reviewed nearly in traditional lecture style to ensure that students are exposed to all of the material. However, once the students have become accustomed to downloading and completing the Modules and Exercises before Lecture, the Instructor begins to rely on the students' prior

reading of the Modules. That is, the Instructor will highlight selected points from the Modules and pose questions based on students' responses to the Exercises that accompany the Module.

After reviewing the Modules, the Instructor provides in-class examples and activities for the related to the Modules. The example problems chosen for the activities are similar to example problems chosen in past years using "traditional" teaching. The key difference is that because the Modules offload some of the "direct" lecturing outside of class, more time is available (typically 1-3 segments of 5-10 minutes each) to allow students to attempt the problems before the Instructor provides complete explanations. During this time, the Instructor and TA help individual students who ask questions, and otherwise walk through the classroom to ensure that everyone is making a serious attempt. Informed by our observations, student feedback, and the literature regarding the role of feedback (recall Section 2.2), we believe that the student initiation of the problem leverages their understanding of the final answer because they can compare the correct answer to their own initial instincts and correct some mistakes in "real time".

In practice, perhaps up to 1/3 of the students require some direct prodding from the Instructor or TA to initiate a serious attempt. One reason that students fail to participate appears to be that it is tedious and time-consuming to copy the problem statement and diagrams into their notebooks. Therefore, in Spring 2010, the Instructor began providing the problem statements and diagrams on Moodle, prior to the Lecture, with the request that students download or copy the problems into their notebooks and be prepared to initiate these problems immediately in Lecture. This seems to have had modest success.

3.3 Problem-Solving Session. The Problem-Solving Sessions immediately follow Lecture on Tuesday and Thursday evenings (6:30pm – 8:00pm; alternate office hours are provided for students with schedule conflicts). The Sessions are advertised as an opportunity to "come and do homework with the professor and the teaching assistant" and under no circumstances are used to deliver new content. Although optional, the Instructor provides direct and indirect incentives to encourage participation, including earning up to 3% of the final grade based on attendance of the Problem-Session. In general, weekly assignments are due on Friday's, rendering the value of attendance on Tuesday and Thursday as roughly equivalent to each other. Students are allowed to attend both sessions per week, but are told that attending once per week is sufficient to earn the full 3% of the final grade. This practice is designed to gently advise students not to overinvest time or to become too dependent on help from others. Also, the once-per-week model alleviates possible congestion, as the capacity of the available room is about 50, and the total enrollment (two sections, Fall 2009) was 76 (in Spring 2010, the Instructor is teaching one section with an enrollment of about 45).

At each Session, the Instructor posts the homework problems on the computer screen at the front of the room. To prompt students to make a serious initial attempt on each problem, the Instructor cycles through the homework problems on the screen about every 30-40 minutes. Students are free to work in groups with other students, and often organize small sub-groups and work together at the board. The Instructor and TA visit

each group to encourage students to take turns acting as "provider" or "receiver". Of course, some students have strong inclinations to seek help by copying answers from other students, thus circumventing the intention of the Session. Once the Instructor and TA identify these students, they periodically sit with these students to ask them questions and help them to work more independently. Nevertheless, in many cases, these interventions do not seem to elicit permanent behavioral changes.

4. Measures of Direct Participation

4.1 Modules. Download histories of the modules from the Moodle site were not kept under the assumption that these are not reliable indicators of the level of seriousness with which students read the modules. However, data of student participation in Exercises associated with the Modules from Fall 2009 was kept and is reported in Table 1.

Table 1. Student Completion of Graded Online Exercises Associated with Module (Fall 2009)

Online Exercise	Raw Participation	Active Enrollment (estimated)	% of Active Enrollment
1	45	75	60.0%
2	37	75	49.3%
3	42	72	58.3%
4	53	72	73.6%
5	45	69	65.2%
6	55	69	79.7%
7	57	66	86.4%
8	54	63	85.7%
9	51	63	81.0%
Average	**48.8**	**69.3**	**70.4 %**

Raw Participation = the number of students who completed the given activity.
Active Enrollment = estimate of total number of active students in the course at a given point in time, based on attendance, submission of homework, and attendance at exams. Active enrollment is not the same as the official enrollment because some students stop attending class without officially withdrawing.

According to Table 1, participation in the online Exercises averaged about 70% for the entire semester, and increased as the semester progressed. This increase is likely due to two factors: (1) the remaining students were more serious than the ones who dropped out, and (2) the Instructor and the students were both more skilled at creating and taking the online exercises. To date in Spring 2010, participation is averaging approximately 81%, which is similar to the participation observed toward the end of Fall 2009.

4.2 Lectures. For Fall 2009, of the 63 students who completed the course (as measured by being present at the final exam), average attendance per lecture was 58.3 (93%). Data for Spring 2010 has not yet been tabulated, but attendance to date is similar.

4.3 Problem-Solving Sessions. Table 2 shows attendance at the Problem-Solving, including comparison with course enrollment. "Total" attendance is the total attendance recorded at both sessions in a given week. "Unique" attendance is the number of distinct students who attend at least one session in a given week. Thus, for a student who attends twice in a week, his or her attendance counts as "2" for Total, but only "1" for Unique.

Table 2. Total and Unique Attendance at Problem-Solving Sessions and Compared with Active Enrollment (Fall 2009).				
Week	**Total Attendance**	**Unique Attendance**	**Active Enrollment (estimated)**	**% Unique Attendance**
1 Aug 18, 20	49	44	76	57.9%
2 Aug 25, 27	69	51	75	68.0%
3 Sept 1	19	19	75	25.3%
4 Sept 8	24	24	75	32.0%
5 Sept 15, 17	55	45	72	62.5%
6 Sept 22, 24	82	53	72	73.6%
7 Oct 20, 22	60	41	69	59.4%
8 Oct 27, 29	55	41	69	59.4%
9 Nov 3, 5	41	36	69	52.2%
10 Nov 10, 12	57	40	66	60.6%
11 Nov 17	13	13	66	19.7%
12 Nov 23	21	21	63	33.3%
13 Dec 1, 3	31	29	63	46.0%
14 Dec 8, 12	24	22	63	34.9%
Average	**42.9**	**34.2**	**69.6**	**49.2%**
Total = total attendance at both Sessions during a given week. Unique = the number of distinct students who attended at least one Session during a given week. Active Enrollment = estimate of the total number of active students in the course at a given point in time, based on attendance, submission of homework, and attendance at exams.				

Low attendance in weeks 3, 4, 11, and 12, as well as the gap from September 24 – October 20, are due to schedule irregularities caused by unplanned events (a hurricane warning and a labor strike). Lower attendance in weeks 13 and 14 is attributed to student "burn-out" at the end of the semester. Unique attendance was above 50% in 8 of the 14 weeks, and peaked at 73.6% in Week 6. Therefore, during most weeks, at least half of the students attended at least one Session. Data for Spring 2010 has not yet been tabulated, but appears to be similar.

5. Student Feedback

We designed and administered a detailed 42-question survey at the end of the course (December 2009) to solicit student feedback on how the course was run and their perceptions of their learning. In order to ensure anonymity, the survey was distributed and managed by an independent assistant in the College of Engineering, using the system Zoomerang. Students submitted their responses electronically and their responses were coded by their final grade category in the course (A/B, C, or D/F; final grades were provided by the Instructor and matched by the independent assistant). All raw responses, identified only by student final grade category, were then provided to us.

The survey was broken into 4 basic parts: Overall, Modules, Lecture, and Problem-Solving Session. It probed several items of concern based on our own suspicions and on informal comments that students gave over the course of the semester. Responses were received from 36/63 students who completed the class, including responses from 14/23 students who earned A/B, 16/23 who earned C, and 6/17 earned D/F.

Technical Notes. In the following tables responses to selected multiple-choice questions are summarized. In general, for each question, the (sometimes abbreviated) question text, question choices, and the total number of respondents for each choice (from the entire pool of 36 respondents) are provided. In addition, a numerical score from 1 – 4 is assigned to each choice, and an "Index" is defined as the average score of all responses, weighted by the number of respondents for each choice. Indices are provided for the entire survey pool ("Composite") and for each sub-pool (A/B, C, and D/F). Although the interpretation of the score depends on the question, the scoring system was standardized such that a score of 4 (1) is generally interpreted to represent a favorable/positive (unfavorable/negative) outcome or comment, though this may not always hold. The reader is advised to interpret the Index for each question only after reading the question statement and response choices. The complete survey text is provided in the Appendix.

5.1 Time and Effort Devoted. Based on our observations, and on informal student comments, students appeared to spend more time in this class, and with more regularity, than compared with other 3-credit courses (we did not explicitly distinguish STEM courses from other courses, but most our students' courses are in math or basic science). Table 3 summarizes results of three questions that indicate that students devoted significant time in this course.

Table 3. Student Perceptions of Time Spent in this Course.

3. Compared with other 3-credit classes, how much time did you spend on this class?			4. Including [Modules, Problem-Sessions, and HW], estimate how many hours per week you spent on this class outside of the Lecture.			5. How would you judge the value of the time that you spent in this class?		
Much more (4)	25	69%	More than 6 hours (4)	12	33%	I spent a lot of time, but it was worth it (4)	19	53%
Somewhat more (3)	10	28%	4-6 hours (3)	19	53%	I spent about the right amount of (3)	6	17%
Somewhat Less (2)	1	3%	2-4 hours (2)	5	14%	I spent a lot of time, but it was not worth it (2)	9	25%
Much Less (1)	0	0%	Less than 2 hours (1)	0	0%	I did not spend very much time, but I should have spent more time (1)	1	3%
No opinion/ decline to respond	0	0%	Don't know/ decline to respond	0	0%	No opinion/ decline to respond	1	3%
Composite Index	3.67			3.19			3.23	
A/B Index	3.71			3.07			3.50	
C Index	3.63			3.31			3.25	
D/F Index	3.67			3.17			2.40	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

The data indicate that the majority of students reported spending more time in this class than for other 3-credit classes. Based on Question 5 (Index 3.23), most reported that the time they spent was "worth it" (19, 53%) or "about the right amount" (6, 17%), but a significant number also reported that it was "not worth it" (9, 25%). This indicates that this course structure made some progress in convincing students that in the long run, it is worth investing significant quality time. However, students earning a grade of D/F felt less strongly about this (D/F Index 2.40 was lower than the Composite Index 3.23).

Further evidence of high student effort is summarized in Table 4. Respondents indicated that the Modules caused them to increase their effort preparing for Lecture (Question 12, Index 3.03), and that the Problem-Solving Session encouraged them to spend time on a regular basis (Question 34, Index 3.48). In both cases, however, these behaviors were much weaker for students earning a grade of D/F than for students earning A/B or C, as evidenced by the low D/F Indices for Questions 12 and 34 (2.33 and 2.60, respectively).

Table 4. Influence of Modules and Problem-Solving Session on Effort Devoted (Fall 2009).

12: To what extent do you agree or disagree: "Because of the Modules, I devoted more effort preparing for the Lecture ahead of time than I normally would have without the Modules".			34: To what extent do you agree or disagree: "The Problem-Solving Session caused me to spend time on this class on a regular basis. Without the Problem-Solving Session, I would have crammed more for exams and learned less".		
Strongly Agree (4)	8	22%	Strongly Agree (4)	18	50%
Somewhat Agree (3)	23	64%	Somewhat Agree (3)	13	36%
Somewhat Disagree (2)	3	8%	Somewhat Disagree (2)	2	6%
Strongly Disagree (1)	2	6%	Strongly Disagree (1)	0	0%
No opinion/decline to respond	0	0%	No opinion/decline to respond	3	8%
Composite Index	3.03			3.48	
A/B Index	3.21			3.54	
C Index	3.13			3.73	
D/F Index	2.33			2.60	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

5.2 Modules and Exercises. We explored student impressions of whether the Modules were clear, including the animated structure. We also inquired whether the Exercises increased their understanding of the Modules. Results are summarized in Table 5.

Table 5. Student Perceptions of Module Design and Corresponding Exercises (Fall 2009).

13. In your opinion, the Modules were			14. The PPT slides for the Modules were "animated" ... Compared with "fixed" slides in which all of the information is presented at once, how helpful was the "animation" to your learning the information?			15. To what extent did the Moodle exercises help you to understand the content of the Modules?		
Very clear and easy to understand	11	31%	Much more helpful	23	64%	Very much	9	25%
Somewhat clear and understandable	16	44%	Somewhat more helpful	8	22%	Somewhat	18	50%
Somewhat confusing and unclear	5	14%	Somewhat less helpful	3	8%	Not very much	7	19%
Very confusing and unclear	3	8%	Much less helpful	1	3%	Not at all	1	3%
No opinion/ decline to respond	1	3%	No opinion/ decline to respond	1	3%	No opinion/decline to respond	1	3%
Composite Index	3.00			3.51			3.00	
A/B Index	3.00			3.36			2.93	
C Index	3.19			3.73			3.00	
D/F Index	2.50			3.33			3.20	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

Based on the results reported in Table 5, the Modules were reasonably clear (Question 13, Index 3.00) and the students predominantly liked the animated nature of the slides (Question 14, Index 3.51). In Question 9 (Index 3.33, not shown in Table 5), 33/36 (92%) indicated that the Modules were either very useful or somewhat useful to their learning. However, only 11/36 (31%, Question 13) indicated that the Modules were "very clear", and they appeared to be less clear to D/F students (Question 13, Index 2.50).

Students also indicated that the online Exercises in Moodle increased their understanding of the Modules (Question 15, Index 3.00). The importance of grading the online Exercises is underscored by the results of Question 16 (Index 2.25, not shown in Table 4) in which 24/36 (66.7%) respondents indicated that they attempted the ungraded questions posed in the Modules "infrequently" or "never". A related concern was whether the students were reading the Modules before class. In Question 10 (not shown in Table 5) most students (25/36, 70%) reported that they "always" or "frequently" read the Modules prior to Lecture, but 10/36 (28%) indicated "infrequently". These results are reasonable and encouraging, but sub-optimal.

Note that a significant number of students were honest in responding that they did not attempt ungraded questions or read the modules before class. This indicates that they felt secure to provide answers that might be viewed unfavorably by the Instructor.

5.3 Examples in Lecture. Overall, students had favorable impressions of the Lectures. In Question 19 (Index 3.31), 32/36 (89%) of respondents found the lectures to be "very useful" or "somewhat useful", though students earning D/F were less enthusiastic (Index 2.83). All respondents (Question 20, 36/36, 100%) indicated that they "always" or "frequently" attended Lecture. This is consistent with actual attendance records (92%, Section 4.2). Further feedback is summarized in Table 6.

Table 6. Student Perceptions of Interactiveness of Lectures (Fall 2009).

22. To what extent do you agree or disagree: "Because some material was introduced in the Modules, the Lecture was used less for lecturing material and more for doing examples and activities".			24. During Lecture, the professor … asked you to start the … exercises on your own (5-10 minutes) before doing them at the board …. Compared to when the professor does the exercise only on the board, how helpful was it for you to first think about the problem before seeing the entire solution?			28. How would you rate the interactiveness of the Lecture – the frequency with which students asked questions and the professor asked questions to the students?		
Strongly agree (4)	13	36%	Much more helpful (4)	15	42%	Very high (4)	20	56%
Somewhat agree (3)	16	44%	Somewhat more helpful (3)	14	39%	Somewhat high (3)	14	39%
Somewhat disagree (2)	5	14%	Somewhat less helpful (2)	3	8%	Somewhat low (2)	2	6%
Strongly disagree (1)	1	3%	Much less helpful (1)	2	6%	Very low (1)	0	0%
No opinion/decline to respond	1	3%	No opinion/decline to respond	2	6%	No opinion/decline to respond	0	0%
Composite Index	3.17			3.24			3.50	
A/B Index	3.43			3.15			3.57	
C Index	3.13			3.47			3.56	
D/F Index	2.67			2.83			3.17	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

As summarized in Table 6, students generally found the Lectures to be activity-oriented, interactive, and beneficial. According to Question 22 (Index 3.17), 29/36 (81%) of students thought that the modules created more space in Lecture for examples and activities. Students also found that having the opportunity to begin the in-class exercises before the Instructor completed them on the board was helpful (Question 24, Index 3.24), although to a lower extent for students earning D/F. Based on Question 28 (Index 3.50), 34/36 (94%) students indicated that they perceived the lectures to be "very highly" or "somewhat highly" interactive. Overall, responses to Question 23 (Index 3.53, not summarized in Table 6), 32/36 (89%) students found the examples in lecture to be "very useful" or "somewhat useful", and this result was uniform for students earning all grades A-F. However, students expressed some discomfort with being called on in class to answer questions (Question 29, Index 2.86), particularly C and D/F students.

We were concerned about possible negative effects of the Modules to modify the use of the Lecture time. Did students feel that the Modules prepared them for Lecture? Because the Instructor was not lecturing on the board, but summarized the PowerPoint slides and did examples, did students feel that some information was not delivered in the Lecture or that it was difficult to take notes? The questions are addressed in Table 7.

Table 7. Student Perceptions of How Information was Delivered and Absorbed in Lecture (Fall 2009).

25. How well did the Modules prepare you to do the examples and exercises during Lecture?			26. Did the professor skip material during Lecture that he should have covered because he assumed that you had already read it in the Modules before the Lecture?			27. How well were you able to take notes during the Lecture, given that many of the notes were already in the Modules and not written on the board?		
Very well/Based on what I read in the Modules, I almost always could understand … the exercises and examples in Lecture	8	22%	Never (4)	19	53%	Very well/no problem (4)	10	28%
Somewhat well/I used information from the Modules, but I needed some additional explanation from the professor … do the exercises … in Lecture	22	61%	A few times (3)	11	31%	Somewhat well/I got used to it (3)	14	39%
Somewhat poorly/I relied mostly on the professor to help me … do the exercises … in Lecture, but I did see how the Modules were related	6	17%	Frequently (2)	2	6%	Not very well/ I missed several ideas (2)	10	28%
Very poorly/I had no idea how the Modules were related to the exercises … in Lecture, and I felt unprepared to do them	0	0%	Always (1)	2	6%	Not well at all/ I prefer copying the notes from the board (1)	1	3%
No opinion/decline to respond	0	0%	No opinion/decline to respond	2	6%	No opinion/decline to respond	1	3%
Composite Index	3.06			3.38			2.94	
A/B Index	3.36			3.50			2.92	
C Index	2.88			3.57			3.00	
D/F Index	2.83			2.67			2.83	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

While the results in Table 7 are positive overall, it is clear that students expressed some discomfort in relying on the Modules to do examples in Lecture (Question 25, Index 3.06), had some concerns that some material was neglected in Lecture (Question 26, Index 3.38, but note that 31% reported "a few times"), and had some difficulty taking notes (Question 27, Index 2.94). Students earning grades D/F indicated more difficulty using and relying on the Modules, as evidenced by the lower D/F indices in Questions 25 and 26.

6. Problem-Solving Session

Most survey respondents indicated that they found the Problem-Solving Sessions "very useful" (Question 31, 26/36, 72%, Index 3.67), and most claimed attendance "all the time" or frequently" (Question 32, 32/26, 89%, Index 3.29). Because the recorded attendance averaged about 50% (Table 2), it is possible that the sample of survey respondents is skewed toward those who attended the Problem-Solving Session regularly. It is also important to note that students earning grade D/F found the Sessions less useful (Question 31, Index 3.00), and attended less frequently (Question 32, Index 2.80), than students earning A/B or C.

6.1 Motivation and Preference to Attend. Further questions probed why students attended the Problem-Solving Sessions and if they found them to be valuable. Responses to Question 33 indicated that 14/36 (39%) claimed "learning a lot" as the primary reason that they attended, but 16/36 (44%) indicated that they felt pressured to attend because they would "fall behind" or be unable to complete the assignments without it. In Questions 35 and 36, the students generally expressed the sense that the Instructor and TA were skilled at answering their questions, and in Question 39, students generally felt that they left the Session understanding what they needed.

In Question 40, when given a binary choice between a course "with a Problem-Session but no solution manual", and one "with a solution manual available but no Problem-Session", the students overwhelmingly preferred the Problem-Session case (29/36, 81%), although students earning grade D/F felt less strongly about this (3/6, 50%). When presented with a the possibility of a budgetary crisis (not so hypothetical!) in which they might need to pay for the Problem-Solving Session beyond the tuition (Question 41), roughly equal numbers of students expressed willingness to pay per session $0 $1, $2 $3, $4, and $5 (average $2.39), and this was relatively uniform across the range of A/B, C, and D/F students.

These responses collectively demonstrate that the Problem-Solving Session is useful to students and that students express demand for it. However, we are concerned that in some cases students are feeling forced to come (couple Question 33 with the expressed concern with the time required for this class, Section 5.1). Also, we are further concerned that in a few cases, students become overly dependent on the Session.

6.2 Interactions with other Students. Another interesting finding of the survey is that students tended to work with other students. In Question 37 (Index 3.03), 26/36 (72%)

indicated that they received help "always" or "frequently", and in Question 38 (Index 3.00), 27/36 (75%) indicated that they helped another student "always" or "frequently". These statistics match our observations from the student behaviors during the session. While we generally regard student interaction as a useful behavior, and ample evidence exists to support the effectiveness of student teamwork[13, 21] there were a few students who clearly were relying on others and showed little ability or interest to solve the problems independently. These results are detailed in Table 8.

Table 8. Student-Reported Interactions in Problem Session (Fall 2009).

37: How often did you receive help from another student (not the professor or asistente) for help during the Problem-Solving Session?			38: How often did you help another student during the Problem-Solving Session?		
Never (4)	12	33%	Never (4)	10	28%
A few times (3)	14	39%	A few times (3)	17	47%
Frequently (2)	9	25%	Frequently (2)	8	22%
Always (1)	1	3%	Always (1)	1	3%
No opinion/decline to respond	0	0%	No opinion/decline to respond	0	0%
Composite Index	3.03			3.00	
A/B Index	2.86			3.36	
C Index	3.13			2.56	
D/F Index	3.17			3.33	

Whole numbers indicate raw number of responses. % are compared to the total of 36 total respondents. The score for each response is noted in ( ), e.g., (4), (3), (2), or (1). The indices are the average scores, weighted by the number of respondents for each choice, excluding "no opinion/decline to respond".

7. Evidence of Learning and Pedagogical Effectiveness

While the student responses to the questionnaire were generally positive, a more difficult question to address is whether students "learned more" as a result of the Inverted method. We therefore attempted to measure learning gains by administering the Concept Assessment Tool in Statics (CATS)[9] as both pre-test (during the first two weeks of the semester) and post-test (during the last week of the semester) to students in the "Inverted" cohort (students enrolled in the Instructor's sections of Statics) and the "Standard" cohort (students enrolled in other sections of Statics at UPRM, in which the Inverted method was not used). We chose to use the CATS because it is accessible[9] and statistically validated[22,23]. Moreover, one of the authors (A. Santiago-Román) has demonstrated the cognitive diagnostic capacity of the CATS and is pursuing research activities regarding the use of CATS to measure student cognition and for formative pedagogical assessment[24,25].

The Instructor directly asked his students ("Inverted") to take pre- and post-test CATS, offering an incentive of 2% of the final grade for each instance. As a result, 65 students took the pre-test (cf. initial enrollment of 76) and 46 took the post-test (cf. final enrollment of 63). The Instructor also asked all colleagues teaching the other ("Standard") sections of Statics to ask their students to take the pre- and post-tests. This generated 36 participants on the pre-test (cf. initial combined enrollment ~250) and 31 on the post-test (cf. final combined enrollment ~200). Incentives among the other

instructors varied, and no data was collected (save for the pre-test data) to establish a common baseline (e.g., student GPA) among the two cohorts.

Table 9 summarizes the total aggregate data and provides p-scores to assess the significance of differences in the test scores. Both raw scores and their corresponding percentages (compared with the maximum possible CATS score of 27) are provided.

Assuming the data to be approximately normal, the 2-tailed, unpaired t-test was used to determine the probability (the p-score) of obtaining the test results given the null hypothesis of identical distributions for the Inverted and Standard cohorts' scores. Typically, p-scores below 0.05 are required to reject the null hypothesis and infer that the distributions of the two data sets differ significantly.

For the pre-test scores, p = 0.43, indicating that the Inverted and Standard cohorts' score distributions cannot be interpreted to differ significantly. Furthermore, the pre-test scores for each cohort (~18%) were close to the random-guessing average (20%) expected on pre-tests of student without prior exposure to Statics[23]. On the post-test, the students in the Inverted cohort outperformed those in the Standard cohort by nearly 2 points (out of 27), and the corresponding p-score p = 0.0076 indicates that this difference is significant.

Table 9. CATS Pre- and Post-Test Scores for Inverted and Standard Cohorts: All Participants (Fall 2009)

	Inverted Cohort				Standard Cohort			
	N	Base Enrollment	Average Score (% correct)	Standard Deviation	N	Base Enrollment	Average Score (% correct)	Standard Deviation
Pre-Test	65	76	4.94 (18.3%)	2.10	36	250	4.61 (17.1%)	1.86
p-score (two-tailed, unpaired) for Pre-Test, Inverted vs. Standard = 0.43								
Post-test	46	63	8.41 (31.2%)	3.62	31	200 (estimated)	6.52 (24.1%)	2.45
p-score (two-tailed, unpaired) for Post-Test, Inverted vs. Standard = 0.0076								
The maximum raw score on the CATS is 27. Base enrollment is the number of students actively enrolled in the course at the time of the corresponding activity.								

However, if the sample is restricted to those students who took both the pre- and post-test CATS, it is possible to calculate the normalized gain <g> for each student[12]:

$$< g > = \frac{\text{POST TEST SCORE} - \text{PRE TEST SCORE}}{27 - \text{PRE TEST SCORE}} (100)$$

The normalized gain <g> measures the student's actual improvement compared with the maximum possible improvement (27 is the maximum score). The restricted Inverted cohort consists of 43 students (cf. 46 total post-test takers) and has an average post-test score of 8.70. The restricted Standard cohort consists of only 11 students (cf. 31 total post-test takers) and has an average post-test score of 7.36. We note that post-test scores from 6 of the 31 Standard post-test scores were excluded from the restricted cohort because they could not be properly identified. The average post-test score of these six students was 6.29. Table 10 summarizes the data for these restricted cohorts.

Table 10. CATS Scores and Gains for the Restricted Cohorts Taking both Pre and Post Tests (Fall 2009)									
Restricted Inverted Cohort					Restricted Standard Cohort				
N	Pre-Test Avg (St Dev)	Post-Test Avg (St Dev)	<g> Avg (St Dev)	Paired p-score	N	Pre-Test Avg (St Dev)	Post-Test Avg (St Dev)	<g> Avg (St Dev)	Paired p-score
43	4.74 (1.81)	8.70 (3.52)	17.5 (16.3)	0.000	11	3.91 (1.56)	7.36 (2.74)	14.9 (11.3)	0.002
Unpaired p-score comparing Inverted Gain (17.5) and Standard Gain (14.9): 0.56 Unpaired p-score comparing Inverted Post-Test Score (8.70) and Standard Post-Test Score (7.36): 0.21									
<g> = Normalized Gain = (Post-test Score – Pre Test Score) / (27 – Pre-test Score). Paired p-score = p-score comparing pre- and post-test results for a given cohort. Unpaired p-score = p-score comparing a result between the two cohorts The maximum raw score on the CATS is 27.									

Within each of the restricted cohorts, p-scores indicate that the difference in pre- and post-test scores is significant (2-tailed, paired t-test); $p = 0.000$ for the Inverted cohort, and $p = 0.002$ for the Standard cohort. Thus, both the Inverted and Standard instruction effected learning gains as measured by the CATS.

The average gain for the restricted Inverted cohort (17.5) exceeded that for the restricted Standard cohort (14.9). However, the corresponding p-score (2-tailed, unpaired t-test) is $p = 0.56$, indicating that the difference is not statistically significant. A similar analysis comparing the post-test scores of the restricted Inverted (8.70) and Standard (7.36) cohorts also shows the difference is not significant ($p = 0.21$).

The discrepancy between the apparent significance of the results for the overall cohorts (Table 9) and the apparent insignificance of the results for the restricted cohorts (Table 10) is possibly explained by reasoning that students who had taken the pre-test have an advantage on the post-test over student who did not take the pre-test. Another explanation is that the average pre-test score for the restricted Standard cohort (3.91/27 = 14.5%) is significantly below the random guessing average (20%) and represents an anomaly, perhaps due to the small sample size.

We further question whether gains derived from sub- 20% pre-test scores are as important as gains derived from the 20% random guessing baseline. For example, is a gain in score from say, 2 → 15 more meaningful than a gain from 5 →15? This is plausible because it might be that the student staring with 2 has engrained misconceptions that are more resistant to change than the errors of the "random guesser" who is not committed to any schema. Yet it is also plausible that the student who begins with 2 is initially committed to a misconception, but is not necessarily resistant to change. Thus, once he or she learns how to correct the misconception, his or her gain will be misleadingly greater than that of the random guesser who also learned the same concepts with similar affinity.

All things considered, given that the Inverted cohort's absolute post-test scores were higher for both the total cohorts (Table 9) and the restricted cohorts (Table 10), and further supporting evidence from Steif & Dollár[27], we are encouraged that the Inverted

model is effective. However, it is clear that more data must be collected to determine if the patterns that we see so far will persist.

We note further that even the Inverted cohort's average post-test score (8.41/27, 31.2%) is at the low end of reported post-test scores from other institutions in the U.S., which range from 32% – 69%[9]. One possible explanation for the low scores is that because English is the second language for nearly all UPRM students, it is possible that language barriers negatively affected the UPRM students' results on the test. To our knowledge, the data reported herein represent the first CATS data derived from a population that is 100% Hispanic and non-native English-speaking. We plan to conduct further research to determine language effects on the CATS.

8. Discussion, Conclusions, and Future Work

We developed, implemented, and began assessing an Inverted Classroom model for Statics during Fall 2009 at the University of Puerto Rico, Mayagüez. From this experience, we have formed a favorable impression of the Inverted method and plan to continue using it for teaching Statics and possibly expand its use to other courses.

Student Reactions. Student feedback was generally positive. In particular, students felt that they learned more, devoted more time, and formed better study habits than compared with traditional classroom approaches. However, in both multiple-choice and free response questions, several students expressed that this course required extra time, perhaps at the expense of other classes, and some felt pressured to attend the Problem-Solving Session in fear that they could not complete the coursework independently.

In several cases, the same student expressed both (conflicting) views, e.g. "I liked the fact that I actually learned at the Problem-Solving Sessions, but I got frustrated at times because I had to stay after class". Since the Problem-Solving Session is devoted for doing homework – an activity that students are expected to perform outside of the Lecture time – we surmise that many students (like this one) who express misgivings about the time required for the Problem-Solving Session were perhaps students who had previously not needed or not chosen to spend quality time on their learning tasks.

Another issue that was raised was that students indicated some difficulty with taking notes in class because traditional lecturing was not done at the board. In addition, the instructor noticed that when Exercises were given in Lecture, too much time was consumed by students drawing or writing the problem before starting it. During Spring 2010, the Instructor now provides some problem templates prior to Lecture so that students can come to class with the problem already copied or printed. This has had modest success so far.

As a general pattern, students earning grades of D/F responded less favorably than other students. For example, the D/F students expressed greater discomfort relying on the Modules as a preparation for in class exercises, and they also appeared to devote a lower level of effort. It is not clear whether this is because D/F students have poorer study

habits, greater attachment to rote learning methods, lower intellectual capacity, greater language barriers, or combinations of these factors. There were a few students whom the Instructor correctly predicted to earn D/F based on their behaviors in the Problem-Solving Session (e.g., over reliance on others for help, and resistance to working independently).

Instructor Reactions. From an instructional viewpoint, the Instructor observed an increase in student attention to the coursework compared with other courses taught in a more traditional manner. In addition, the Inverted method allowed the Instructor more time to provide activities during Lecture compared with traditional settings. This allowed him to better implement his philosophies of structured problem-solving procedures[11] and multiple-method problem solving (solving a given problem by more than one method and comparing the alternative methods)[26].

The Instructor acknowledges spending a great amount of time during Fall 2009 to create the Modules and Exercises from scratch (probably 6-8 hours per week). During Spring 2010, about 3 hours per week were required to update the Modules, Exercises, and Homework assignments. Up to one additional hour per week is spent reviewing student performance on the pre-lecture Exercises.

The Problem-Solving Sessions do require additional time and effort on the part of the Instructor. But since he is fortunate to have a TA, he does not have to grade papers, and he much prefers spending additional face time with students to grading. In practice, the two 90-minute sessions per week really consume 4-5 hours per week, and the additional office hour brings the total to 5-6 hours per week. This is significantly more than the institution's expectation of 3 office hours per week. To address this, the Instructor is beginning to enforce the 90 minute duration of the sessions somewhat more regularly, and is helping students to become comfortable with the idea of initiating all problems to the point of "threshold" understanding, but not necessarily to full completion. Even so, the weaker students are usually unable to initiate the entire assignment in 90 minutes.

The Instructor favors the Inverted Classroom as an excellent class management strategy. All preparations for Lecture are completed at least 48 hours in advance, save for a brief time spent reviewing the student performance immediately prior to Lecture, and so he never has to cram to prepare notes just before class. The Modules and Exercises also allow for a clear way to deliver the course schedule and scaffold graded exercises.

Assessment of Learning Gains. Results from the post-test scores on CATS indicated that both the Inverted and Standard modes of instruction effected significant learning gains. The post-test scores for the Inverted cohort exceeded those of the Standard cohort, both for the entire cohorts and the restricted cohorts consisting of students who took both the pre- and post-tests. While analysis of the entire cohorts indicated that the difference was significant, analysis of the restricted cohorts did not. We believe that this latter analysis suffered from small sample size and other irregularities with the data from the Standard cohort. We believe that the Inverted method is superior to traditional teaching, but further supporting evidence is necessary to edify this claim.

Absolute CATS scores were at the bottom of the range typically earned by students at other institutions in the U.S. We are in the process of determining if there is any baseline data (e.g. student entry-level skills, SAT scores, etc.) that might partially explain this. We also suspect that English is enough of a barrier for many of our students as to have had a negative impact on their CATS scores.

In addition to using the CATS, the Instructor had originally intended to compare performance of his UPRM students with that of his former students at UW-Milwaukee on a set of exam problems that were common or similar to both groups. However, this was abandoned in light of variations in overall course and exam format, problem weights, and possible language barriers.

Future Work. The Engineering Mechanics Committee in the Department of General Engineering at UPRM manages the mechanics courses that are required for all baccalaureate engineering students at UPRM (C. Papadopoulos is the coordinator of this Committee). The Committee is beginning to conceive a Common Module approach to standardize the teaching of Statics. As part of this development process, our Inverted Classroom model presented here, and that of Dollár & Steif/OLI will be evaluated by our colleagues for use in delivering the Common Modules.

We have not undertaken a comprehensive evaluation of the OLI Statics course, and the limited feedback that we have from students is mixed (see Question 17 of the survey in the Appendix). However, we are generally impressed with this system, and very impressed with its sophisticated, interactive environment and the real time feedback provided to students. The OLI has about 300 interactive learning activities[27] compared with about 15-20 built into our system. Moreover, the OLI modules have superior flow control and seamless mingling of content and exercises. In contrast, students using our Modules must manually switch pages to go from the Module to the Exercise. We plan to work with our IT staff to increase sophistication using Moodle.

However, the advantage of our system is that the content of the Modules and Exercises is readily customized and modified by the Instructor. This flexibility might be especially important for our environment with bilingual students. In contrast, the content of the OLI modules cannot be changed by the instructor.

During the coming year, we hope to conduct a more thorough evaluation of both our system and that from the OLI, and ultimately determine which platform is most appropriate for use by us and our colleagues in the Engineering Mechanics Committee. However, regardless of which system is used, we have a favorable impression of the Inverted Classroom method, and plan to continue its use with an appropriate platform.

Acknowledgements

The authors thank the reviewers for many useful and pertinent comments that directly informed the revisions of the final version of this paper.

References

1. Lage, M., G. Platt, and M. Treglia. "Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment", Journal of Economic Education, Winter 2000, pp. 31-43.
2. Dollár, A. and P. Steif. "A Web-based Statics Course using and Inverted Classroom". Proceedings of the ASEE Annual Conference & Exposition, Austin, TX, June 2009.
3. Toto, R. and H. Nguyan. "Flipping the Work Design in an Industrial Engineering Course" , 39th ASEE/IEEE Frontiers in Education Conference, San Antonio, TX, October 2009.
4. G. Gannod. "WIP: Using Podcasting in an Inverted Classroom", 37th ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI, October 2007.
5. Open Learning Initiative, http://oli.web.cmu.edu/openlearning/. Last visited, March 12, 2009.
6. Papadopoulos, C., W. Frey, M. Castro-Sitiriche, D. Lorenzo, and E. O'Neill. "Using an Inverted Classroom Model in the Social, Ethical, and Global Issues (SEGI) in Engineering Program", 19th Annual Meeting, Association for Practical and Professional Ethics, Cincinnati, OH, March 2009.
7. Moodle, http://moodle.org/. Last visited March 12, 2009.
8. Papadopoulos, C. Moodle course page for INGE 3031 Engineering Mechanics:Statics, University of Puerto Rico, Mayagüez. https://moodle.uprm.edu/course/view.php?id=513. Guest login is permitted using keycode "papadopoulos".
9. Concept Assessment Tool for Statics. Available at www.engineering-education.com. Last visited March 12, 2010.
10. Prince, M., "Does Active Learning Work? A Review of the Research," Journal of Engineering Education, Vol. 93, No. 3, pp. 223–231, July 2004.
11. Papadopoulos, C. "Assessing Cognitive Reasoning and Learning in Mechanics", Proceedings of the ASEE Annual Conference & Exposition, Pittsburgh, PA, June 2008.
12. Hake, Richard R. "Interactive Engagement vs. Traditional Methods: A Six Thousand Student Survey of Mechanics Test Data for Introductory Physics Courses", American Journal of Physics 66(1), pp. 64-74, January 1998.
13. Beichner, R.J. "A Student-Centered Active Learning Environment for Undergraduate Programs", white paper, National Academy of Sciences, 2008. Available at http://www.ncsu.edu/per/allpublications.html, last visited March 10, 2010.
14. Froyd, J. and M. Ohland. "Integrated Engineering Curricula", Journal of Engineering Education, Vol. 94, No. 1, pp. 147-164, January 2005.
15. Dannenhoffer, J. and J. Dannenhoffer. "Development of an Online System to Help Students Successfully Solve Statics Problems", Proceedings of the ASEE Annual Conference & Exposition, Pittsburgh, PA, June 2008.
16. Taraban, R., E.E. Anderson, A. DeFinis, A.G. Brown, A. Weigold, and M.P. Sharma. "First Steps in Understanding Engineering Students' Growth of Conceptual and Procedural Knowledge in an Interactive Learning Context", Journal of Engineering Education, Vol. 96, No. 1, pp. 57-68, January 2007.
17. Chen, J.C., J.A. Kadlowec, and D.C. Whittinghill. "Concepts Learning Using Technology for Rapid Feedback and Student Engagement", Proceedings of the ASEE Annual Conference & Exposition, Portland, OR, June 2005.
18. Bransford, J.D., Brown, A.L., and Cocking, R.R., eds., How People Learn: Brain, Mind, Experience, and School, Washington, D.C.: National Academy Press, 2000.
19. R.C. Hibbeler. Engineering Mechanics: Statics, 12th ed., Prentice Hall, 2010.
20. Plesha, M., G. Gray, and F. Costanzo. Engineering Mechanics: Statics, McGraw Hill, 2009.
21. Smith, K. "Cooperative Learning". A reference guide available at http://www.ce.umn.edu/~smith/docs/CLHks.pdf. Last viewed March 12, 2010.
22. Steif, P. S., & Dantzler, J. A. A Statics Concept Inventory: Development and Psychometric Analysis. Journal of Engineering Education, Vol. 94, No. 4, pp. 363-371, October 2007.
23. Steif, P. and M. Hansen. "New Practices for Administering and Analyzing the Results of Concept Inventories". Journal of Engineering Education, July 2007.
24. Santiago Román, A. I. Fitting Cognitive Diagnostic Assessment to the Concept Assessment Tool for Statics. PhD dissertation, Purdue University, 2009.

25. Santiago Román, A.I., R. Streveler, P. Steif, and L. DiBello. "The Development of a Q-Matrix for the Concept Assessment Tool for Statics", Proceedings of the ASEE Annual Conference & Exposition, Louisville, KY, June 2010.
26. Papadopoulos, C., J. Bostwick, and A. Dressel. "Promoting Holistic Problem-Solving in Mechanics Pedagogy", Proceedings of the ASEE Annual Conference & Exposition, Honolulu, HI, June 2007.
27. Steif, P. and A. Dollár. "Study of Usage Patterns and Learning Gains in a Web-based Interactive Static Course". Journal of Engineering Education, October 2009.

Appendix: Questionnaire

The following is the text of the Questionnaire provided to students in the Inverted Cohort at the conclusion of the Fall 2009 (actually conducted electronically via Zoomerang).

Survey: INGE 3031 Statics, Sections 096 and 116, Prof. Christopher Papadopoulos, Fall 2009

Purpose and Use of Data. Your responses to this survey are very important to understanding your experience in this class and will be used to improve future offerings of this class both at UPRM and at other Universities. Aggregate results will be compiled and presented to other educators through meetings, conference presentations, and written publications. None of these results will reveal your identity.

Confidentiality. To ensure that your identity remains confidential and to encourage your honest feedback, your responses to this survey will be automatically sent directly to Sr. Arturo Ponce in the College of Engineering. The professor (Christopher Papadopoulos) will NOT see any of the responses until after the final grade has been submitted to the Registrar. After this point, Sr. Ponce will match your responses to your course grade. The professor and other educators will see your responses identified only by your grade, but not by your name.

Your Rights. You have the right to decline participation in this survey and to stop taking the survey at any point during the survey. Your participation in this survey will NOT affect your course grade in any manner.

Part I. Overall Evaluation. This class was taught using a structure consisting of three main activities: (1) Modules prior to Lecture, (2) Lecture, and (3) Problem-Solving Session after Lecture (supplemented by traditional office hours).

1. The professor organized and delivered this structure
   a. Very well b. Somewhat well c. Somewhat poorly d. Very poorly
   e. No opinion/decline to respond
2. Compared to a regular "lecture-only" class with no Modules and only office hours in the professor's office, what was the level of your learning in this class?
   a. Much higher b. Somewhat higher c. Somewhat lower d. Much lower
   e. No opinion/decline to respond
3. Compared with other 3-credit classes, how much time did you spend on this class?
   a. Much more b. Somewhat more c. Somewhat Less d. Much Less
   e. No opinion/decline to respond
4. Including reading the Modules, using Moodle, attending the Problem-Solving Session, and writing your homework papers, estimate how many hours per week you spent on this class *outside of the Lecture*.
   a. More than 6 hours b. 4-6 hours c. 2-4 hours d. Less than 2 hours
   e. Don't know/decline to respond
5. How would you judge the value of the time that you spent in this class?
   a. I spent a lot of time, but it was worth it
   b. I spent a lot of time, but it was not worth it
   c. I spent about the right amount of time
   d. I did not spend very much time, but I should have spent more time
   e. No opinion/decline to respond
6. Rank the following in terms of how important they were to your learning in this class (7 = most important, 1 = least important).

a. Modules	7	6	5	4	3	2	1
b. Lecture	7	6	5	4	3	2	1
c. Problem-Solving Session	7	6	5	4	3	2	1
d. Class notes	7	6	5	4	3	2	1
e. Homework	7	6	5	4	3	2	1
f. Textbook	7	6	5	4	3	2	1
g. Exam Regrade	7	6	5	4	3	2	1

7. Rank the following in terms of how important they were for studying for an exam (6 = most important, 1 = least important).

a. Modules	6	5	4	3	2	1
b. Lecture	6	5	4	3	2	1
c. Problem-Solving Session	6	5	4	3	2	1
d. Class notes	6	5	4	3	2	1
e. Homework	6	5	4	3	2	1
f. Textbook	6	5	4	3	2	1

8. Would you choose to take a course from this professor (Papadopoulos) again?
   a. Definitely b. Probably c. Probably not d. Definitely not
   e. No opinion/decline to respond

Part II. Evaluation of Modules

9. Overall, rate the usefulness of the Modules to your learning.
   a. Very useful b. Somewhat useful c. Somewhat useless d. Very useless
   e. No opinion/decline to respond

10. How often did you read the Modules before each class?
    a. All the time b. Frequently c. Infrequently d. Never
    e. No opinion/decline to respond

11. Rank your reasons for reading the Modules before Lecture (4 = most important reason, 1 = least important reason).

a. It is was required by the professor	4	3	2	1
b. They were well designed and I learned a lot from them	4	3	2	1
c. They were convenient to read while I was online	4	3	2	1
d. I wanted to earn the participation points in my final grade (3/100)	4	3	2	1

12. To what extent do you agree or disagree: "Because of the Modules, I devoted more effort preparing for the Lecture ahead of time than I normally would have without the Modules".
    a. Strongly agree b. Somewhat agree c. Somewhat disagree d. Strongly disagree
    e. No opinion/decline to respond

13. In your opinion, the Modules were
    a. Very clear and easy to understand b. Somewhat clear and understandable
    c. Somewhat confusing and unclear d. Very confusing and unclear
    e. No opinion/decline to respond

14. The PPT slides for the Modules were "animated" to allow you to click the forward and back buttons within each slide to see how the information is logically developed and to alert you to important ideas and insights. Compared with "fixed" slides in which all of the information is presented at once, how helpful was the "animation" to your learning the information?
    a. Much more helpful b. Somewhat more helpful c. Somewhat less helpful
    d. Much less helpful e. No opinion/decline to respond

15. To what extent did the Moodle exercises help you to understand the content of the Modules?
    a. Very much b. Somewhat c. Not very much d. Not at all
    e. No opinion/decline to respond

16. Most of the Modules contained questions in the slides that you were *not* required to write on paper or complete on Moodle. How often did you attempt these questions on your own (for example, by trying them in your notebook)?
    a. All the time b. Frequently c. Infrequently d. Never
    e. No opinion/decline to respond

17. Earlier in the course, we occasionally used modules from the Open Learning Initiative (OLI). Please provide any comments that indicate your experience with these modules.

18. Please leave any comments about the Modules. **[FREE RESPONSE BOX]**

Part III. Lectures

19. Overall, rate the usefulness of the Lectures to your learning.
    a. Very useful b. Somewhat useful c. Somewhat useless d. Very useless
    e. No opinion/decline to respond

20. How often did you attend the Lecture?
    a. All the time b. Frequently c. Infrequently d. Never
    e. No opinion/decline to respond

21. Rank your reasons for attending the Lecture (4 = most important reason, 1 = least important reason).

a. It is required to receive Economic Assistance	4	3	2	1
b. There were activities and good examples	4	3	2	1
c. The professor explained things well	4	3	2	1
d. I wanted to earn the attendance points in my final grade (3/100)	4	3	2	1

22. To what extent do you agree or disagree: "Because of the Modules, the Lecture was used less for lecturing material and more for examples and activities".
    a. Strongly agree b. Somewhat agree c. Somewhat disagree d. Strongly disagree
    e. No opinion/decline to respond

23. The examples and exercises in Lecture were generally
    a. Very useful b. Somewhat useful c. Somewhat useless d. Very useless
    e. No opinion/decline to respond

24. During Lecture, the professor frequently asked you to start the examples and exercises on your own (for 5-10 minutes) before doing them at the board with the entire class. Compared to when the professor does the exercise *only* on the board, how helpful was it for you to first think about the problem before seeing the entire solution?
    a. Much more helpful b. Somewhat more helpful c. Somewhat less helpful
    d. Much less helpful e. No opinion/decline to respond

25. How well did the Modules prepare you to do the examples and exercises during Lecture?
    a. Very well/Based on what I read in the Modules, I almost always could understand how to do the exercises and examples in Lecture
    b. Somewhat well/I used information from the Modules, but I needed some additional explanation from the professor to understand how to do the exercises and examples in Lecture
    c. Somewhat poorly/I relied mostly on the professor to help me understand how to do the exercises and examples in Lecture, but I did see how the Modules were related
    d. Very poorly/I had no idea how the Modules were related to the exercises and examples in Lecture, and I felt unprepared to do them
    e. No opinion/decline to respond

26. Did the professor skip material during Lecture that he should have covered because he assumed that you had already read it in the Modules before the Lecture?
    a. Never b. A few times c. Frequently d. Always
    e. No opinion/decline to respond

27. How well were you able to take notes during the Lecture, given that many of the notes were already in the Modules and not written on the board?
    a. Very well/no problem b. Somewhat well/I got used to it
    c. Not very well/ I missed several ideas d. Not well at all/ I prefer copying the notes from the board
    e. No opinion/decline to respond

28. How would you rate the interactiveness of the Lecture – the frequency with which students asked questions and the professor asked questions to the students?
    a. Very high b. Somewhat high c. Somewhat low d. Very low
    e. No opinion/decline to respond

29. How did you feel when the professor asked you a question during the Lecture?
    a. Very comfortable b. Somewhat comfortable c. Somewhat uncomfortable
    d. Very uncomfortable e. No opinion/decline to respond

30. Please leave any comments about the Lectures. **[FREE RESPONSE BOX]**

Part IV. Problem-Solving Sessions

31. Overall, rate the usefulness of the Problem-Solving Sessions to your learning.
    a. Very useful b. Somewhat useful c. Somewhat useless d. Very useless
    e. No opinion/decline to respond

32. How often did you attend the Problem-Solving Sessions?
    a. All the time b. Frequently c. Infrequently d. Never
    e. No opinion/decline to respond

33. Rank your reasons for attending the Problem-Solving Session (3 = most important reason, 1 = least important reason).
    a. I liked coming because I felt that I learned a lot 3 2 1
    b. I felt that I had to attend because otherwise I would not be able to do the homework and I would fall behind other students 3 2 1
    c. I wanted to earn the attendance points in my final grade (3/100) 3 2 1

34. To what extent do you agree or disagree: "The Problem-Solving Session caused me to spend time on this class *on a regular basis*. Without the Problem-Solving Session, I would have crammed more for exams and learned less".
    a. Strongly agree b. Somewhat agree c. Somewhat disagree d. Strongly disagree
    e. No opinion/decline to respond

35. During the Problem-Solving Sessions, how skilled was the professor in helping you resolve your questions?
    a. Very skilled b. Somewhat skilled c. Not very skilled d. Not skilled at all
    e. No opinion/decline to respond

36. During the Problem-Solving Sessions, how skilled was the asistent (Angel Figueroa) in helping you resolve your questions?
    a. Very skilled b. Somewhat skilled c. Not very skilled d. Not skilled at all
    e. No opinion/decline to respond

37. How often did you receive help from another student (*not* the professor or asistente) for help during the Problem-Solving Session?
    a. All the time b. Often c. Infrequently d. Never
    e. No opinion/decline to respond

38. How often did you help another student during the Problem-Solving Session?
    a. All the time b. Often c. Infrequently d. Never
    e. No opinion/decline to respond

39. How often did you leave the Problem-Solving Session feeling that even though you spent time, you did not understand the problems?
    a. Never b. A few times c. Frequently d. Always
    e. No opinion/decline to respond

40. Based on your experience in this course, state your preference:
    a. I prefer a course in which there is a Problem-Solving Session, even if the homework answers are not available in a solutionary
    b. I prefer a course in which homework answers are available from a solutionary, but there is no Problem-Solving Session
    c. No opinion/decline to respond

41. It is possible that more Problem-Solving Sessions could be offered if more student asistentes could be hired to assist the professors, but the University budget is unable to provide this. How much would you be willing to pay *per Problem-Solving Session* in order to ensure that they could be offered in your future classes?
    a. $5 b. $4 c. $3 d. $2 e. $1 f. $0 g. No opinion/decline to respond

42. Please leave any comments about the Problem-Solving Sessions. **[FREE RESPONSE BOX]**

Part V. Open Feedback

43. Please leave any general comments and suggestions that will help improve this class in the future, including what you liked and did not like about this class. **[FREE RESPONSE BOX]**