Flipping the Classroom on an Established Introduction to Engineering Design Course

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***Abstract* - The University of Maryland administers a project-based "Introduction to Engineering Design" course taken by approximately 1000 first-year students each year. Teams of students are tasked to design, build and test an autonomous hovercraft that meets a demanding set of product specifications. The project requires students to learn and apply engineering principles in order to make informed design decisions. The "traditional" instructional model has a single content expert lecture to all students through a series of 50-minute anchor lectures taught on the first six Fridays of the semester. Each anchor lecture is taught multiple times with four sections (or up to 190 students) attending the lecture together. The anchor lectures are fortified with discussions led by an instructor to his/her section of 40-50 students. Anecdotal feedback indicates these lectures are far too fast paced and content packed, assume students have too much prior knowledge, and lack sufficient engagement between the lecturer and the large number of students present. A pilot section "flipped" the classroom by replacing the content taught during the traditional lecture sequence with a series of recorded, web-based lecture segments covering the same information. Students were surveyed in both the "traditional" and the "flipped" course offering to rate the effectiveness of these lectures. Students rated the blended learning approach more effective than the traditional approach in every category assessed, stating what they liked best to be "When something was unclear, you could rewind, and hear the explanation. You could also pause to take notes, as well as refer back to the actual lecture for homework problems." These initial results indicate that pedagogical changes incorporating blended learning approaches can enhance the student experience within an engineering design course.**

Index Terms – Blended learning, First-year programs, Flipped classroom, Keystone program

INTRODUCTION

The University of Maryland administers a well-established, project-based "Introduction to Engineering Design" (ENES 100) course each year to approximately 1000 first-year engineering students [1]. The course has been taught in its current format since 2006 when the Keystone Program was formed [2]. Students enrolled in ENES 100 are required to design, build and test an alpha prototype of an autonomous hovercraft that must meet a demanding set of product performance specifications. Students complete this project on multidisciplinary teams of about 10 students. The project requires students learn and immediately apply engineering principles within fluid mechanics, electronics, rigid body dynamics and controls theory in order to make informed design decisions. The "traditional" instructional model has a single content expert lecture to all students on one of these topics. This is accomplished through a series of 50-minute anchor lectures taught on the first six Fridays of the semester. Each anchor lecture is taught multiple times with four sections (or up to 190 students) attending the lecture together. The anchor lectures are fortified the following week with two 110-minute discussions led by an instructor to his/her section of 40-50 students. Anecdotal feedback from students has been that these lectures are far too fast paced and content packed, assume students have too much prior knowledge, and lack sufficient engagement between the faculty member lecturing and the large number of students in the classroom.

During the spring 2013 semester, a pilot section of ENES 100 attempted to combat these criticisms by flipping the classroom. The content taught during the traditional Friday lecture sequence was replaced with a series of recorded, web-based lecture segments covering these same topics. Each week students were expected to watch three to five 'short' videos (23 minutes on average with one lasting 40 minutes) and complete an online quiz to insure comprehension of each video segment. Each video was filmed in the state-of-the-art Seigel Learning Center at the University of Maryland. The medium for each talk included a set of PowerPoint slides that were distributed electronically to all students prior to watching the videos. The facility permitted on-slide annotation (Khan Academy-like), embedded high-definition video, overlay video of the presenter and multiple breakout cameras for visual demonstrations of hardware and other lecture props. The only post-production editing performed was selecting the start and end times for each video segment. While the average weekly duration of these lectures increased from 50 minutes in the traditional lecture hall to 83 minutes in the flipped lecture model, students in the flipped lecture model had the opportunity to watch each video at increased playback rates (1.25x and1.5x were commonly used). The full usage of technology was encouraged, though students were urged to slow down (and even rewind) when something presented was unclear to them.

Students were surveyed in both the "traditional" and the "flipped" course offerings to rate the effectiveness of these lectures. Students rated the flipped classroom model more effective than the traditional approach in every category assessed. These initial results provide a clear indication that pedagogical changes which incorporate technology and blended learning approaches can enhance the student experience within an introduction to engineering design course.

BACKGROUND

Over the last seven years, first-year engineering students at the University of Maryland have been tasked with designing, constructing and testing an autonomous hovercraft as part of a course-wide design competition. It is assumed that entering students have had no prior engineering, physics or robotics experience when beginning the course. Students receive just-in-time instruction on all technical aspects required to complete this project. In order to provide teams with the technical knowledge necessary to design an autonomous hovercraft, six technical lectures are given. These lectures are:

- Introduction to hovercraft and levitation (week 1)
- Propulsion and fans (week 2)
- Basic electronics (week 3)
- Introduction to the Arduino and sensors (week 4)
- Hovercraft dynamics (week 5)
- Practical aspects of hovercraft control (week 6)

It is important to realize that the main goals of this course are to teach students engineering design analysis, the product development process and teamwork while also introducing students to the engineering discipline in a way that excites students with the prospects of an engineering career [2].

This is the only engineering course that all engineering majors at the University of Maryland require as part of their degree program. This includes aerospace, bioengineering, chemical and biomolecular, civil and environmental, electrical and computer, fire protection, materials science, and mechanical engineering students. Approximately one-third of students are undecided engineering majors when enrolled in this course. Considering the demographics of the enrolled students, a course philosophy favoring breadth of exposure over depth of understanding has been adopted. For example, fluid mechanics is taught at a level necessary to complete the project and teams are expected to use these principles to make informed design decisions. While principles such as conservation of mass, momentum and energy are introduced and used to size and select levitation and propulsion fans, the coverage of these topics occurs in less than eight hours. Many students will enroll in one or more fluid mechanics classes later in their curriculum in which the topics introduced will be covered at a proper depth to prepare students for the expectations of their respective majors.

The Introduction to Engineering Design course is the Keystone Program's signature course. The Keystone Program is a cross-disciplinary collection of faculty from all eight departments within the college of engineering who share the responsibilities of teaching this course. The goal of the Keystone program is to ensure first and second-year students are provided unparalleled instruction in fundamental engineering topics in an environment that fosters their growth and development during their most formative stage. This is accomplished by properly balancing challenge with the support required for students to be successful [3]-[4]. The autonomous hovercraft project is an incredibly challenging project. In a great semester, about one-third of all teams who begin the project will create a product that meets all of the stated product specifications. In a poor semester, no team may accomplish this goal during one of their three official timed trials. Success is not measured by meeting all required product specifications, but instead by the learning that occurs through the experiential learning process.

Our experience indicates that, by and large, students are more energized by working to solve very difficult problems than being asked to provide a cookie-cutter solution to a simple problem that requires little intellectual thought or grit. At each stage of the process students receive support from dedicated teaching faculty members, an undergraduate teaching fellow that spends each class period with their assigned section, laboratory technicians and undergraduate laboratory teaching fellows. Additionally, students have access to all other faculty and teaching fellows assigned to the course during posted office hours and open lab hours. The point of this commentary is to highlight the fact that a lot is asked of students within this course, but that regular and meaningful contact with senior faculty and teaching assistants occurs, particularly within a hands-on laboratory setting. The motivation for flipping the classroom was to enhance meaningful student-faculty interactions and to provide students with additional time within the laboratory, not to reduce faculty teaching load or contact time with students.

DESCRIPTION OF SURVEY

A survey was generated to poll students in both the traditional and flipped classroom sections. The traditional and flipped section response rates were 90% (n = 43) and 100% (n = 34), respectively. The survey was conducted during week 11 of a 16-week semester. The final technical lecture was given in week six of the semester.

The first question asked pertained to each students overall impression of the six technical lectures provided at the start of the semester. A five-point Likert scale was used ranging from "Very ineffective" to "Very effective." Results are presented as the mean value of the sample responses and are assigned a numerical value of 5 for "Very effective" down to 1 for "Very ineffective." Students were asked to provide a ranking of the overall effectiveness of these six technical lectures along with how effective the lectures were at providing them with:

- The knowledge to design an autonomous hovercraft
- A presentation that kept you engaged in the material being taught
- A resource to use to complete homework assignments
- A resource to use when troubleshooting shortcomings in your hovercraft design
- A resource to use when troubleshooting shortcomings in your hovercraft prototype

The second survey question asked students to rank the effectiveness of each of the six technical lectures. These rankings were provided on a slider scale ranging from 0 = Very ineffective to 100 = Very effective.

A final set of questions invited written comments from students. The three prompts in which comments were invited are:

- What did you like most about the six technical lectures presented this semester?
- What did you like least about the six technical lectures presented this semester?
- What would have allowed you to get more out of the six technical lectures presented this semester?

A comparison of survey means between groups was analyzed for statistical significance using the statistical analysis tools available in Microsoft Excel. Specifically, a two-tailed *t*-test was performed (using the T.TEST function), specifying a test for two samples with unequal variance. The critical threshold for a statistically significant difference in the means was taken to be P<0.05.

Results and Discussion

I. Overall Effectiveness

The first survey question administered sought to determine how effective the technical lecture sequence was perceived by the students in the traditional and flipped sections. Students in both the traditional and flipped lecture sections were asked to rate the overall effectiveness of the instruction provided. A clear improvement was identified with the flipped classroom lecture model. The mean of the flipped lecture model was 4.35, a relative increase of +0.72 over the traditional lecture model (P[<0.001]).

The statistically significant improvement indicated for the overall effectiveness with the flipped lecture model was also observed when specific course components were targeted to determine the effectiveness between the two instructional models (Table I). Major improvements were observed (P[<0.001]) for all cases except for the effectiveness of the lecture model in providing students with a resource to use to complete homework assignments (P = 0.003). This may be attributed to the fact that the homework assignments were written each week by the individual assigned with giving that week's traditional lecture.

TABLE I

AVERAGE RESPONSE FROM STUDENT SURVEYS ON THE OVERALL EFFECTIVENESS OF THE TRADITIONAL AND FLIPPED LECTURE MODELS. SCALE WEIGHTING IS BASED ON 1 TO 5 (1 = VERY INEFFECTIVE, 3 = NEITHER EFFECTIVE NOR INEFFECTIVE, 5 = VERY EFFECTIVE)

How effective were these lectures at providing you with:	Traditional	Flipped
The knowledge to design an autonomous hovercraft	3.72	4.50
A presentation that kept you engaged with the material being taught	3.23	4.21
A resource to use to complete homework assignments	3.93	4.50
A resource to use when troubleshooting shortcomings in your hovercraft design	3.53	4.26
A resource to use when troubleshooting shortcomings in your hovercraft prototype	3.40	4.21

One of the most interesting results obtained between the two models was in response to the query on the effectiveness of these lectures at providing a presentation that kept students engaged with the material being taught. The flipped model had the largest relative increase over the traditional lecture in this category (+0.98). This is an interesting result when you consider the stigma that online education lacks the engagement of face-to-face lectures. The author attributes the student acceptance of this flipped format to the limited number of hours of web-based instructional materials required and the significant amount of in-person contact time spent between the faculty member and students following each video lecture.

II. Individual Lecture Effectiveness

A second survey question was asked to determine how effective each week's lecture was in both the traditional and flipped lecture models. These results are as perceived by the students in these sections. The results of this survey question are summarized in Table II.

TABLE II

AVERAGE RESPONSE FROM STUDENT SURVEYS ON THE EFFECTIVENESS OF EACH TECHNICAL LECTURE PROVIDED THIS SEMESTER. SCALE WEIGHTING IS BASED ON 0 TO 100 (0 = VERY INEFFECTIVE, 50 = NEITHER EFFECTIVE NOR INEFFECTIVE, 100 = VERY EFFECTIVE)

Weekly technical lecture	Traditional	Flipped
Introduction to hovercraft and levitation	68.8	86.1
Propulsion and fans	72.2	87.9
Basic electronics	65.2	80.1
Introduction to Arduino and sensors	65.1	79.5
Hovercraft dynamics	69.9	86.8
Practical aspects of hovercraft control	69.3	84.4

The flipped lecture model was ranked more effective than the traditional lecture model in all categories. The results are statistically significant (P[<0.001]) each week with the exception of the lecture on Introduction to the Arduino and sensors (P = 0.002). An increase of +15.7 was observed between the mean of the six traditional lectures and the six flipped lectures.

A more interesting observation is the fact that with both instructional models the least effective lectures were identified to be the same (basic electronics and introduction to the Arduino and sensors). By the end of the semester, almost all teams identify electronics and programming/ controls as the two most difficult facets of this mechatronics project. It is troubling to observe that these lectures are found to be least effective, as they are the aspects of the project with which students struggle the most. This data provides a clear indication that additional time must be spent on these topics in future course offerings.

III. Student comments

The final survey questions were open-ended prompts where students were asked to provide written comments on the aspects of the lecture model received that they liked most, liked least and would like to see changed. A significant number of comments were received. The results for the traditional lecture model are summarized in Table III and for the flipped lecture model in Table IV.

TABLE III
STUDENT COMMENT SUMMARY FOR THE TRADITIONAL LECTURE MODEL (43 RESPONSES)

Summary question	Response (frequency)
Liked Most	Material presented in a basic, straightforward and informative manner that was useful to the design task (18) Variety of teachers with multitude of experience and opinions (10) Slides were posted and helped with homework (4) Applicability of specific lectures to project (4)
Liked Least	Lectures very boring and lacked engagement (14) Lectures moved too quickly; content overwhelming; some information repetitive or not helpful; assumed students had more prior knowledge than they do (10) Large, warm lecture hall on Fridays at lunch time (7) Electronics and Arduino lectures did not properly prepare students for project requirements (4)
Would Change	Make lectures more exciting/interactive/engaging (11) Provide a preview before each lecture (6) Provide more examples / practice with new concepts (6) Change lecture structure – wide variety of suggestions on how best to accomplish this (12)

TABLE IV
STUDENT COMMENT SUMMARY FOR THE FLIPPED LECTURE MODEL (34 RESPONSES)

Summary question	Response
Liked Most	"I loved that they were web based lectures. When something was unclear, you could rewind, and hear the explanation. You could also pause to take notes, as well as refer back to the actual lecture for homework problems." (19) The use of multimedia, demonstrations and worked out example problems (4) Organization of lectures (in depth on a single topic); informative and helpful to project by covering all necessary topics (3)
Liked Least	The videos were too long (9) The information provided on electronics and Arduino (6) Logistical issues – trouble watching at increased speeds; need for more worked examples; too fast paced; had to maximize video to clearly see screen (5) Could not ask the professor questions as easily (3)
Would Change	"I think having sample problems worked out maybe as a supplementary document, especially for the electronics section." (8) "More interactivity with the teacher. Perhaps a live virtual questions section." (3) Shorter more precise lectures (3) Logistical issues – pop out video features; add a transcription; post videos further in advance; better quiz comprehension questions; additional ungraded practice problems; refined topical coverage (8) Nothing (5)

The results obtained from student's written comments provide a clear indication of the aspects of the instructional model they liked most, least and feel should change. Students in the traditional lecture model favored having material presented in a straightforward fashion by a variety of faculty members who freely share their experience and opinions in a way that is directly applicable to the design task and, to a lesser extent, weekly homework assignments. These characteristics are all achievable in a flipped lecture model. What students liked least and feel should change about the traditional lecture model was the lack of energy and interactivity between the lecturer and the very large number of students crammed into the lecture hall. Additionally, many felt the content provided was far too fast-paced, assumed students had too much prior knowledge and did not cover the more difficult aspects of the course at a sufficient level (likely because little to no time was available to work sample problems). A flipped lecture model can effectively respond to many of these student concerns.

More than 50% of the students sampled in the flipped lecture model indicated that what they liked most was having control of when and how they receive the instructional materials and being able to rewind when an explanation provided was not clear or a refresher was needed to complete an assignment.

What students liked least about this instructional model was the duration of the videos provided. The intention was to film ~10 minute video segments, though all ran considerably longer than this target duration. Some of this can be attributed to a lack of proficiency teaching within the new instructional facility (longer time was spent using the onscreen annotator than would be required on a chalkboard, shortcuts for clearing the annotator screen quickly were not known until later recording sessions, etc.). Time was spent introducing the video segment contents at the beginning and summarizing the key points at the end of each video. While this may be omitted without a major loss to student's comprehension of the technical material, no complaints were received regarding this inclusion. Additional time savings could occur by simply posting supplementary videos with worked out example problems and/or demonstrations instead of having these embedded within the technical lecture. While no overall time will be saved if students review all materials as expected, the overall viewing experience may be enhanced due to the inclusion of shorter and more targeted video segments.

Additional recommendations made were related to logistical issues (for example, increased playback rates are possible only after the lecture file is downloaded). Many of these issues can be resolved for future offerings now that the issues have been brought to light.

COURSE EVALUATIONS

A final source of data that has been examined to evaluate the learning outcomes between the traditional lecture and flipped model was obtained through the online course evaluation system used for all engineering courses at the University of Maryland. All students were provided an opportunity to complete this survey during the final two weeks of the semester. In total, 23 out of 48 students in the traditional lecture section and 27 out of 34 students in the flipped section submitted course evaluations. The evaluation uses a 5-point Likert scale ranging from 0 = Strongly disagree to 4 = Strongly agree. A summary of the mean student response to select survey questions is provided in Table V.

TABLE V
AVERAGE STUDENT RESPONSE TO SELECT QUESTIONS ASKED ON A FORMAL COURSE EVALUATION CONDUCTED NEAR THE END OF THE SEMESTER. SCALE WEIGHTING IS BASED ON 0 TO 4 (0 = STRONGLY DISAGREE, 2 = NEUTRAL, 4 = STRONGLY AGREE)

Question	Traditional	Flipped
The course was intellectually challenging.	3.13	3.52
I learned a lot from this course.	3.35	3.67
My ability to apply knowledge of engineering principles has improved…	3.32	3.41
My ability to use computers to solve engineering problems has improved…	2.82	2.85
My ability to identify, formulate, and solve engineering problems has improved…	3.28	3.41
My ability to design and conduct experiments has improved…	2.82	3.04
My ability to analyze and interpret data has improved…	2.91	3.11
My ability to design a component, system or process to meet desired needs has improved…	3.28	3.30
My ability to function effectively as a part of a team has improved…	3.32	3.33
Taking this class has increased my awareness of the need to continually upgrade my technical knowledge base and skills.	3.45	3.33

None of the trends identified in Table V pass the statistical significance test for $P < 0.05$. Nonetheless, the results are interesting and worthy of discussion. Students in the flipped lecture model found the course to be more intellectually challenging (+0.39, $P = 0.051$). The reason for this is unknown and the result unexpected. Possible causes for this discrepancy could be that these students entered the course less academically prepared, the video segment followed by a comprehension quiz was intellectually stimulating or the faculty assigned to these sections biased the section in other ways when motiving their students to complete the project. A related result is that students in the flipped model generally felt they learned more from the course (+0.35, $P = 0.07$), yet concluded the course with less awareness for the need to continually upgrade their technical base and skillset (-0.12, $P = 0.5$).

The most interesting results summarized below are those results that only marginally improved with the flipped lecture model. These include:

- My ability to use computers to solve engineering problems has improved as a result of taking this course (+0.03, $P = 0.9$)
- My ability to design a component, system or process to meet desired needs has improved as a result of taking this course (+0.02, $P = 0.9$)
- My ability to function effectively as part of a team has improved as a result of taking this course (+0.01, $P = 0.94$)

The above results are interesting because they indicate that it is highly unlikely that there is any relationship between the lecture model implemented and these learning outcomes. This is not a surprising result, as the flipped lecture model was not implemented to address any of these learning outcomes. It is reassuring to know that students in both the traditional and flipped course models complete the course with the same confidence to use computers to solve engineering problems, to design a component to meet a need and to function as part of a team.

A PARADIGM SHIFT

Following the tabulation of the survey data collected, the Keystone faculty assigned to teach the Introduction to Engineering Design course unanimously decided to teach all sections of this course in the flipped format beginning in the fall 2013 semester. All video segments will be re-recorded to better address the students concerns that were aired (shorter durations, more precise presentations, content experts providing talks, supplementary videos with worked out examples, etc.). However, the replacement of traditional lectures with recorded ones is just the start of the paradigm shift. In fact, this is the easiest step of all.

The paradigm shift that must occur is not in the replacement of in-class lectures with recorded lectures but instead with how a faculty member utilizes the contact time freed up to enhance student learning. In the past, many of these discussion periods (two per week at 110-minutes each) provided a review of the content filled lecture students attended the prior Friday, with some time allotted for hands-on laboratory activities. The fact that the rote lecture material is continually available to students at all hours of the day and night, usually within seconds, means that significant amounts of in class time no longer needs to be used to review the theory covered the prior week unless requested by the students. At current, it is not known how best to use this time. However, the author believes the time will be used most effectively by:

- Spending more time discussing how engineers make design decisions to properly size and select components
- Spending more time in laboratory settings in which students can explore electronic components, microcontrollers, testing apparatus, etc.
- Beginning the prototype construction and testing process earlier in the semester

In the pilot flipped section, the first two objectives were accomplished. However, the overall course was not restructured and so it was not possible to begin prototype construction and testing sooner. Quite a bit of work remains. And as with any design process, it will likely require refinement through multiple iterations before the end product has been optimized.

CONCLUSION

The successful application of blended learning strategies occurred by flipping the classroom in an unlikely course, Introduction to Engineering Design. Students were surveyed in a traditional lecture section and a pilot flipped classroom section to assess the effectiveness of each instructional model at providing students with the technical information they require to complete a very challenging engineering design project. In all categories assessed, students found the flipped classroom lecture model to be more effective than the traditional lecture model. These results are significant and indicate with near certainty that the flipped classroom was a more effective pedagogical model for providing students with the technical content required in this course. The decision to immediately flip the classroom on all future Introduction to Engineering Design course offerings at the University of Maryland was unanimously made after reviewing these compelling survey results. This important decision to adopt the flipped classroom pedagogical model provides an exciting starting point for future activities that will seek to enhance student learning even further. This will occur by learning how best to use the additional informal faculty/student contact time afforded by a flipped classroom model within the unique engineering design course setting.

ACKNOWLEDGMENT

The author would like to acknowledge and thank Professor William Fourney, director of the Keystone Program, for his tireless efforts, forthright leadership style, and exemplary dedication which have greatly contributed to the rise of the undergraduate engineering program at the University of Maryland. His weekly mentoring and candid conversations are cherished. The author would also like to thank the staff of the Arnold E. Seigel Learning Center for the technological support provided to record, edit and make available high-quality instructional materials to the students in the pilot flipped classroom section. In particular, special thanks go to executive director James Zahniser, assistant director Marty Ronning, AV engineer Doug Adams, and the numerous technical directors who made this pilot not only possible, but a truly enjoyable learning experience. Lastly, the author would like to thank Dean Darryl Pines for fully supporting faculty as they explore new instructional models that utilize blended learning and for the continued support he will provide to the Keystone faculty as they experiment with and refine how best to enhance student learning and meaningful faculty-student interactions within an introduction to engineering design course that has been flipped.

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