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A Flipped Model to Develop Improved Problem Identification & Development Skills in a Mechanics of Materials Course

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Introduction:

It has been observed that while students exiting the mechanics of materials curriculum at Rose-Hulman are proficient in applying the mechanics of materials approach to resolve fully formulated and well-structured problems, there is a deficiency in identifying, formulating, and solving such problems when presented with a general engineering system. Prior iterations of the course have focused the face to face meeting time on developing the mechanics of materials theory and applying it to sanitized problems (e.g. standard problems from a text). However, application and extension of the material beyond these sanitized problems often fell to the full responsibility of the student outside of class meeting times due to limited face to face time.

The goal of this effort was to address this deficiency by implementing a flipped model for course content delivery. By delivering the core material asynchronously using video lectures, and monitoring students' comprehension of the core material using developed online tools, class-meeting times can be reallocated to instruction and guidance on how to extend the material using tools such as case studies, problems drawn from research / industry, and more complex multidisciplinary problems. It is hypothesized that by allocating more face to face time to guiding and instructing the students in the decomposition of real, physical problems into resolvable systems, students will become more proficient at applying the material to future applications.

The outcomes for this effort are benchmarked in multiple manners, including exam performance and design project performance. These benchmarks are then compared against concurrent sections of the course using the traditional model, as well as prior sections of the course taught using the traditional model to develop data regarding student performance both with the classical aspects of the course, as well as the extension of the material.

Course Structure:

The course structure was developed and implemented in the Moodle Learning Environment [1]. All aspects of the course with the exception of Exams, Case Studies, and Design Projects were administered and evaluated within the environment. The material was partitioned into 8 Modules corresponding to the fundamental topics covered in the course—analogous to the chapters of the textbook. For this Statics & Mechanics of Materials II course, the Modules were: Introduction, Torsion, Beams in Bending, Stress Transformations, Pressure Vessels, Combined Loading, Deflection of Beams, and Column Buckling. The lengths of each Module was variable, from 1 day in-class equivalent time up to nearly 2 week in-class equivalency. Each Module was then further partitioned into anywhere from one to six Topics, each topic corresponding to roughly 1-2 days of in-class equivalent time—analogous to sections in the textbook.

The content within each Topic followed the same general structure (Figure 1) comprised of a portion to be completed before the in-class meeting time, a portion to be completed during the in-class meeting time, and a portion to be completed after the in-class meeting time. For the portion to be completed before class, the students were first presented with the learning objectives for each Topic. Then, the students were asked to view a lecture video on the topic with the videos ranging from 5-20 minutes. The lecture video was primarily comprised of a screen-capture of the instructor discussing the background, development, and derivation of the topic. The students were supplied workbooks to fill-in and follow along with the lecture—these workbooks were often 1-3 pages in length. Upon completion of the lecture video, the students were prompted with a Muddiest Points questionnaire where they could anonymously note any topics or concepts that were unclear upon completion of the preparatory portion of the topic. After finishing the videos, the students were presented with a Content Quiz to assess their retention and understanding of the content of the videos. These quizzes were generally 3-5 qualitative questions regarding the Topic content and the students were permitted to use any notes, review the video, or consult their textbook to answer the questions. Over the entire course, these quizzes accounted for 5% of the students' final grade.

- Module (8 Total)
  - Topic (1 – 6 per Module)
    - Learning Objectives
    - Activities
      - Lecture Videos
        - Workbook
        - Muddiest Point Questionnaire
      - Content Quiz
      - Concept Questions
      - Practice Problems (Optional)
      - Assessment Questions
  - Case Study (4 of 7 Modules)
  - Design Project (3 of 7 Modules)

Figure 1: Hierarchical Structure of Course

For a given topic, it was expected that the students were to view the lecture video and complete the Content Quiz prior to the 50-minute in-class meeting time. This was enforced by closing the

Content Quiz at the start of each corresponding lecture period. The in-class meeting time was typically structured in the same fashion. The time would begin by addressing any concerns brought up in the Muddiest Points Questionnaire. Then, the instructor would demonstrate the given topic on a basic example problem. Next, the students would then be asked to complete an intermediate-difficulty problem on their own. Following a sufficient amount of time, the instructor would then demonstrate the intermediate problem for the class. Finally, time permitting, a more difficult, application-based problem would then be demonstrated. In most instances, due to time constraints, the problem was only set-up and formulated rather than solved to completion. To conclude the in-class portion of the course, a series of Concept Questions were discussed. These questions reinforced the fundamental concepts and principals of the topics and how they could be extended beyond what had been covered in the course to date.

For students who wished to see additional example problems, each Topic contained a series of Practice Problems, which allowed the students to attempt to solve problems of varying difficulties. A video of the instructor solving each problem was made available online as well for students who struggled with the problems. The Practice Problems were made optional for the students to complete for a number of reasons. First, one of the goals of this flipped model was to encourage to take ownership of their learning and be able to accurately assess their understanding of the material, as it has been shown to significantly increase the effectiveness of the learning process [2]. Secondly, one common complaint from students in flipped course models is the increase in work [3]. As such, instead of using the traditional homework model of requiring the students to complete a specified number of drills of a given topic before performing a summative assessment, it is the responsibility of the students to determine the necessary amount of practice—as this number will likely vary greatly from one student to the next.

Following the in-class portion of the course, the only remaining required component of the students was to complete the Assessment Questions. Each Topic contained between 1-5 Assessment Questions, which were analogous to the traditional problems at the end of a section in the textbook. These questions were evaluated via a competency-based model [4] where the student must get the problem correct to obtain any credit for completing the problem. To discourage random guessing, a 10% penalty per problem was assessed for an incorrect response and the student was given another attempt at the problem. The Assessment Questions accounted for a total of 5% of the students' final grade in the course.

Following the completion of a Module in the Moodle learning environment, 2-3 days in class were then reserved to explore more holistic applications of the material through more complex multidisciplinary examples, case studies, and design problems. The goal of these problems is to address the deficiency that has been observed in the students' ability to extend the fundamental principles of the course beyond traditional textbook-like problems and to more application-based problem. Examples of the case studies utilized in the course include the computation of the factor of safety of the wing spar of a Boeing 747, the computation of the wing tip displacement of the same Boeing 747, and the computation of the factor of safety for a Dodge Challenger's driveshaft during a drag race. In each of these case studies, the students were presented with a brief introduction of the problem and its background, but very limited data or guidance on how to decompose the problem. Then, working in pairs, the students were tasked with developing and implementing a solution approach. Approximately one hour of class time was allocated per case study for doing this so that the instructor was available for consultation. The students then reported their results in the form of a brief memo where they detailed their solution process and the assumptions / simplification that were made to arrive at the solution. These case studies accounted for 4% of the students' final grade in the course.

Additionally, in two of the modules—Torsion and Combined Loading—the students were given open-ended design problems to design components of an engineering system. In these two problems, the students were evaluated solely based upon the quality of their results rather than the quality of their work. This approach was meant to be more representative of what a student might encounter working in industry, where errors that might disregarded as minor in the classroom could have large repercussions (e.g. mixing radii and diameters, units, algebra errors, etc.). For the projects, the students worked individually and submitted a brief memo with their process, documentation, and results. The two projects accounted for 6% of the students' final grade in the course.

For summative assessment, three midterm examinations and one final examination were administered in the course. Each midterm examination was written to be completed in the 50-minute class meeting time while the final examination was allocated four hours. These examinations accounted for 80% of the students' final grade in the course.

Results & Discussion:

The assessment of the outcomes from the above course structure was evaluated in multiple manners. Although the delivery of the material has changed dramatically from past years, the majority of the assessment methods used in the course (exam structure, projects, etc.) remain unchanged. Additionally, seven sections of the course are taught concurrently, using common exams and projects, while only one is using the flipped model detailed above. This will provide quantitative data to assess student performance on exams and projects compared to prior years, as well as other sections who are presented with the same assessments.

The data from the four exams and the projects can be seen in Table 1.

	Flipped Course in Fall 2017 (N = 28)	Concurrent Sections (F17) (N = 138)	Results from Fall 2016 (N = 57)
Exam 1	77.2%	75.4%	77.8%
Exam 2	87.5%	83.8%	85.3%
Exam 3	79.5%	77.8%	81.0%
Final Exam	74.3%	73.9%	74.8%
Projects	81.3%	64.8%	57.5%

Table 1: Student Performance on Common Material

In Table 1, the first column of data represents the performance of the students in the flipped section of the course. The second column of data represents the performance of the students in the other five sections of the course offered concurrent to the flipped section. It should be noted that all exams and projects were identical in these two sets of data, so direct comparisons can be made. The third column of data represents the performance of the students in the two sections of the course taught by the instructor in the prior year. It should be noted that while the final exam remained unchanged from 2016 to 2017, all other exams and projects were different, so direct comparisons are not able to be made as easily.

From the above data, it can be observed that there is no statistically significant effect on the exams as a result of the flipped course. This result is not unexpected, as student exam performance in the course had generally been deemed acceptable in the past and improving the exam scores was not the fundamental motivation behind flipping the course. However, in the above data, it is clear that there is a marked improvement in the project scores—both from the prior year and compared to the concurrent sections of the course. These results, while given a limited sample size, seem to indicate that the flipped course structure and subsequent emphasis on application of the material to more complex engineering problems appears to result in an improved understanding of the applications of the material outside of traditional textbook problems.

For a more qualitative assessment, student performance on case studies can be explored as a measure of their ability to extend the principles of the information to more application-based problem solving settings. While there is no historical data on case studies to serve as a basis of comparison, as case studies were a new implementation in this course, the overall student performance seemed to indicate an understanding of how to extend the material. Regardless of performance, though, the primary motivation behind these case studies was more to expose the students to such extensions in a controlled setting rather than serving as an assessment tool.

Additionally, in the course evaluations that are administered at the end of the course, there are sections where the students are able to evaluate the quality of their learning in the course, the quality of the course, and how well the teaching methods contributed to such results. The data from the flipped section of this course can then be compared to prior sections by the instructor, as well as other sections of the course offered at the institute, as seen in Table 2.

	F17 (Flipped) (N = 28)	**F16 (Same Instructor) (N = 57)**	**2012-2017 Across all Sections**
Quality of Learning	4.57	4.08	3.93
Work Load of Course	3.21	2.37	2.84
Overall Course Rating	4.57	3.96	3.86
Professor used Teaching Methods	4.86	4.59	4.24

Table 2: Average Student Evaluation Results

For the data included in Table 2, the students were asked to evaluate the corresponding topic on a scale from 1-5 with a score of 1 indicating a response of "Poor" while a score of 5 indicates "Excellent". The first column in Table 2 represents the numerical results from student evaluations for the flipped section of the course. The second column represents the numerical results from the prior year when the same instructor had taught two sections of the same course. The final column represents an aggradation of the numerical results for all sections of the course over the prior 5 years.

While the sample sizes are relatively small, a few trends can be noted from the data in Table 2. First, the students' assessment of their own quality of learning was found to be significantly higher in the flipped section of the course than in the prior version, as well as the average across all other sections of the course. While this this perception of an improvement in the quality of learning could be attributed to multiple sources, one such source could be the emphasis on having the students take ownership of their own learning and development in the course rather than having all tasks prescribed to them.

Additionally, of note is that the perceived workload of the course also improved (e.g. amount of perceived work went down). This result could be attributed to the fact that that overall number of required "drill" problems was dramatically decreased and moved to be optional problems for the students to complete if they deemed it necessary.

Both the overall course rating and use of teaching methods were also evaluated more favorably than prior years or in other sections of the course. It can be inferred from this data that the students responded favorably to the structure of the course. This inference was backed up by many of the comments received in the evaluations which echoed this sentiment.

Finally, for an assessment on student engagement with the material, the Moodle learning environment tracks student usage statistics for all portions of the course contained within the environment. While there is far too much data to all be presented in this space a few representative samples shall be considered.

First, looking at the course as a whole, the number of student views in the course and submitted posts (included Content Quizzes, Practice Problems, and Assessment Questions) was tracked over the course timeline. It is observed that while there is weekly variability among the data (likely attributed to times when more emphasis was on in-class elements or the course, or simply academic breaks), the overall activity level of the students remained relatively constant throughout the quarter.

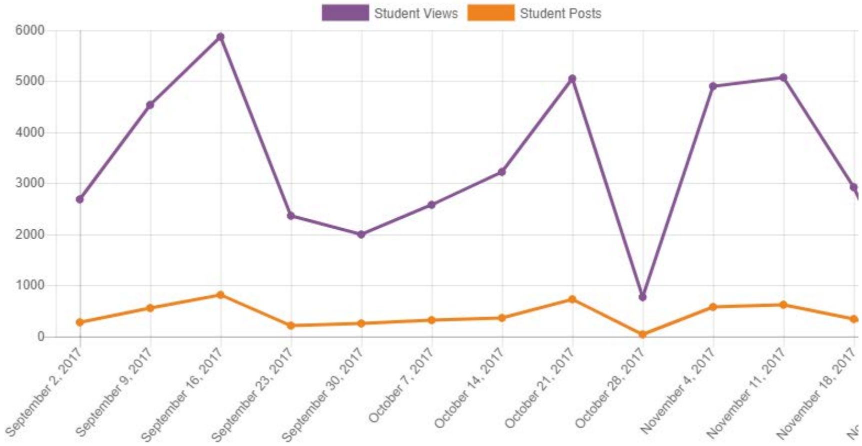

Figure 2: Student Activity Summary

Looking at more specific elements of the course provides additional detail with the students' interaction. For instance, consider the lecture videos that were posted online and required for students to view. Over the entire course, each video had an average of 27.2 unique students view the video (out of 28 total in the course) with an average of 48.6 views per video. Looking further into the timestamps of when the students interacted with the content provided additional insights. During the time prior to the in-class meeting and discussion of each topic, it was common for the times at which the students watched the video to be highly variable, with the 1:00am – 2:00am hour actually being the most popular time frame over the entire course. Additionally, it was seen that the majority of the views for each video fell within two time frames: shortly before the in-class meeting discussing the specified video's content, and shortly before the exam on that content. From the data, and from the comments in the student evaluations, it appeared that the students appreciated and made use of the opportunity to review the online material at later instances in the course if they had assessed their own knowledge of the subject to be insufficient. Having the material directly available to the students at all times helped to encourage the engagement in the course as well.

Summary:

The primary goal of implementing a flipped course in the mechanics of materials curriculum was to improve the students' ability to extend the principals developed in the course to applied problems. Given the preliminary data at the outcome of the course, specifically the dramatically increased performance on the applied design projects and the case studies, it can be tentatively concluded that this goal can be accomplished through such a setting. However, additional data will need to be collected from the cohort of students as they progress further through the curriculum to reinforce this conclusion, though.

In addition to the primary goal, a few other results were of note. By transitioning much of the required "drill"-type problems to become optional practice problems, no noticeable decile of exam scores were noted. This reduction in required student-hours of work allowed for the implementation of more applied problem-solving in class, aiding in the accomplishment of the primary goal. Additionally, due to the availability of nearly all course material on-demand through the online learning environment, students were found to interact with the material quite frequently, which appeared to aid in individual student learning.

References:

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[4] Lunev, A, Petrova, I, & Zaripova, V. *Competency-based Models of Learning for Engineers: A Comparison*. Eurpoean Journal of Engineering Education, Vol. 38, Issue 5. 2013