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Leveraging Curriculum to Mitigate Engineering Killer Courses

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Work in Progress: Leveraging Curriculum to Mitigate Engineering Killer Courses

Historically Engineering curriculums dropout rates have hovered around 50% over the past 60 years despite attempts to mediate the losses. Most students don't enjoy Calculus, Differential Equations, or Physics. Moreover, given the heavy course load at typically engineering schools it is very difficult for some students to adjust to the rigor. This paper details attempts to reinforce difficult topics like physics by having coordination between other courses in the curriculum. In particular, we couple mathematical modeling course problems with the introduction Physics course all engineers must take. The traditional mathematical modeling course includes random calculus and physics problems in the text, but these do little to help the average student struggling with physics. What we did that was different was to include specific problems from each chapter in the modeling course at the same time as they are covering the materials in Physics class. The hope is that this additional time spent on the topic will enable struggling students the additional push needed to successfully complete Physics. The process was started in the last academic year. For completeness we also included specific examples of how this was accomplished.

Introduction

The American Society for Engineering Education (ASEE) reports that 40% to 50% of engineering students drop out or change their majors [1]. There are three key reasons that students leave the engineering curriculum. These include poor teaching and advising, the high level of difficulty in a typical engineering curriculum, and a problem with the student feeling that he/she belongs [2]. Knight et. al. [1] points out that on average 40% of engineering students leave the program before graduation. Knight further reports that these losses are higher for minorities and women. Meyer and Marx [3] report that while many K-12 schools strive to prepare students for engineering; engineering graduation rates have stayed stagnant or have seen further declines. An increase in STEM activities in primary and secondary school have increased the flow into the engineering pipeline and once they are in college, Project Based Learning (PBL) [4-7] and other techniques have proven effective in engaging students in the program. Even with these curricular changes, students continue to drop out of engineering programs at a higher rate than in other programs.

Success in Physics is based on both strong calculus skills and the ability to learn physics concepts, which is often mired with misconceptions [8]. Tyson [9] found that high achievement in high school calculus was related to college physics outcomes in college. However, many students do not take college level calculus while they are still in high school and at our institution, and ~20% even require remedial algebra in their first semester. The already challenging nature of the conceptual nature of Physics along with many of our students coming in with sub-standard math skills, contributes to Physics Mechanics being a course that ~10% of our students need to re-take or leave the major. This aligns with data from other studies where calculus-based Physics is in the top twenty killer course in the engineering curriculum [10].

Approach

We completed this study at a small, liberal arts institution with 400-500 total engineering students across all majors and all class years. All engineering students take calculus-based Physics-

Mechanics (PHY160) during the spring semester of their first year. PHY160 is a 5-credit course that meets for nearly 2.5 hours three days a week that combine lecture and laboratory together. Two professors are always present in the classroom to provide additional opportunities to answer student questions. There are two textbooks used in the course. "*Exploratory Physics*" by (name omitted for anonymity) is used as an in-class workbook that includes active-learning activities and integrated laboratories [11, 12]. "*Fundamentals of Physics*" by Halliday, Resnick and Walker is used for before and after class for prior reading and homework assignments [13]. Some of the topics covered include vectors, linear and rotational motion, Newton's laws, friction, work and energy, conservation of linear and angular momentum, collisions, and moment of inertia. In addition to foundational physics principles, the course has a heavy focus on teaching students how to develop a solution to a problem while reinforcing their critical thinking skills. The problem-solving method for all questions requires students to explicitly write out their approach in the following steps: *Given, Find, Figure, Plan, Assumptions, Estimations, Solution, and Reflections* [14]. As PHY160 is taken during the first year, the requirement of the problem-solving approach on all homework and exams and lays the foundation for a good engineering and science problem solving approach that will help them as they progress into upper level-engineering classes.

However, many students initially resist the provided steps for problem solving. At the beginning of the semester, students complain that the strategy is lengthy and 22% of students do not see the benefit, while 19% of students said that the method helped them avoid making mistakes [14]. At the end of the semester, 52% of students reported that the method got easier with time, while the number of students who said it helped them avoid mistakes or find mistakes increased to 22% and 30%, respectively [14]. Our intervention was designed with two things in mind; 1) If we reinforced the problem-solving strategy in more classes, it would help them catch their mistakes in PHY160 and 2) if we helped students visualize challenging topics, such as vectors, using computational techniques, they would be able to apply those concepts better in PHY160. We hypothesize that achieving either outcome could improve the passing rate of PHY160 based on either enhanced problem solving for enhanced content mastery.

The same semester as PHY160, students take EGR150: Computation Methods in Engineering. This course introduces students to methods for solving physics calculus and engineering problems using MATLAB and Excel during two, 2-hour course sessions per week. These two hours are broken into one hour of lecture and one hour of lab for student to apply and get help with what they are learning. This course uses Amos Gilat's book on MATLAB [15] and teaches students basic programming skills and how to develop algorithms to solve problems in a variety of engineering disciplines. Plotting and other graphical techniques help students visualize the results of their work. Students also make use of various computational techniques including matrix solution of a system of linear equations and symbolic math. The book applies an array of math and science problems in each section that reinforce programming techniques, but these problems do not directly align with our curriculum. Instead of using the book problems, we changed one problem on each homework set to directly match with the current PHY160 curriculum and required the students to use the problem-solving strategy to arrive at a MATLAB based solution. This provided additional examples to the students of how the problem-solving strategy is universally applicable in engineering sciences, but also additional practice with breaking down physics problems in a new context.

We surveyed students taking both classes in Spring 2021, the second year that we attempted to integrated EGR150 with PHY160. We wanted to determine 1) how well correlated our students felt the two classes were, 2) how they were integrating EGR150 into their general PHY160 knowledge, and 3) if they thought the integration should continue in future years. To understand which population of students the integration was impacting the most, we asked students to self-report their current cumulative grade in PHY160.

Example

Engineering students often struggle with trajectory problems, whether in calculus, physics or later on in dynamics. In **Figure 1**, we show the solution to a typical trajectory problem from *Holiday and Resnick 10th ed.* Problem 4.48 pp87 V1 [13] that was assigned as a homework problem in EGR150 approximately 5-6 weeks into the semester. The problem statement is: *A ball is thrown up onto a roof landing making contact with the roof h = 20m t = 4.0s later. The balls path just before landing is* $\theta =$ *60.0 degrees with the roof.* Students are asked to find: a) *Find the horizontal distance d traveled? b) What is the magnitude of the velocity and angle of the ball when it is thrown?* Appendix B contains the full MATLAB solution. Using the equations of motion $s = s_0 + v_0 t + \frac{at^2}{2}, v = v_0 + at$, and the appropriate directions the students can readily find the solution to this problem.

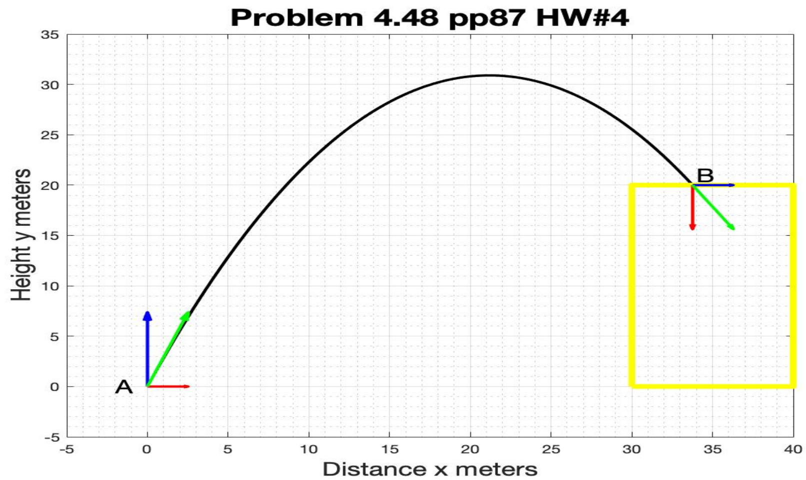

Figure 1. MATLAB output plot from ball trajectory example solution.

As many of our students struggle to understand vectors, the great benefit of doing a problem like this in MATLAB is that they can directly visualize the three vectors describing motion at the start and end of the trajectory. Additionally, MATLAB provides a symbolic means to check their analytical solutions. Some students will realize that the problem can be worked in either direction. In other words, if the ball was thrown from the roof at B landing at A or visa-versa, it is will result in identical speeds and directional angles at impact and launch varying only in direction, which demonstrates a deeper conceptual understanding of the material.

Student Feedback

Students feel that PHY160 and EGR150 are mostly well aligned. We asked our students to rank on a scale from 1-5 (1 being totally dissimilar and 5 being completely similar) how well the timing of the content and the problem-solving strategy matched between PHY160 and EGR150. The students ranked the content correlation at an average of 3.7/5 and the problem-solving correlation at 4.3/5; exact results are shown in **Figure 2**. One student commented, "[the computational methods] physics problems drag behind [physics] class after exam 2 or 3. The MATLAB way of solving physics problems is very different than the physics way." This student, as well as others,

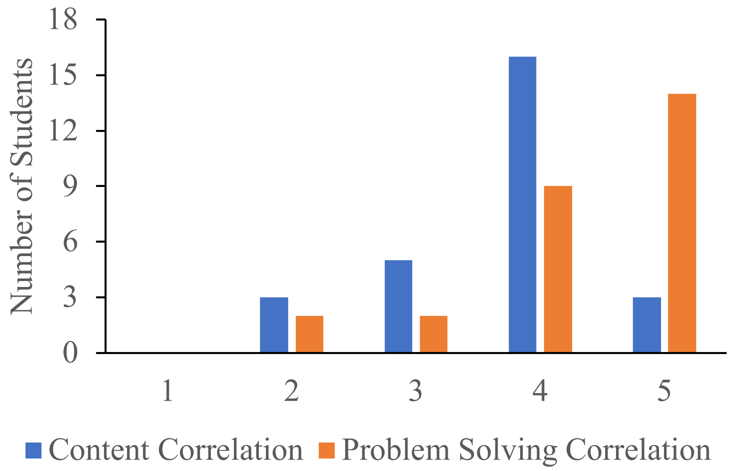

Figure 2. Most students felt that the two courses had room for improvement with the content correlation while most students recognized that the problem-solving approach was the same.

noted that the content is not perfectly synced, which is a key area for improvement for future years. Interestingly, this student also indicated that he/she was focused on how different it was to solve a problem in MATLAB vs. by hand in PHY160. This seems to be a theme among a handful of students who are not always realizing that the problem-solving strategy is the key element that is consistent across all physics problems but focusing rather on the way the strategy is implemented to obtain a solution. Another student commented, "being taught multiple different ways can cause confusion."

Integration of course content leads to improved perception of general knowledge and vectors. We analyzed thought-process questions based on student grade categories by traditional letter grades (>90, 80-90, 70-80, <70) to determine how our intervention was impacting our students in danger of failing PHY160. Of the students who completed the survey, only 3/27 were currently scoring <70 in PHY160. To make more robust conclusions we would need a larger sample size in this grade range. All data presented is based on correlated averages of at least two questions that included a positive and negative approach such as "I think the problem-solving strategy with given, find. etc. is helpful" and "I think the problem-solving strategy with given, find. etc. is unhelpful." All questions were provided on a 1-10 scale with 1 being "doesn't describe me at all" and 10 being "perfectly describes me." Exact questions are provided in Appendix A. Our students are generally not actively visualizing the plots they generate in MATLAB to help them think about problems conceptually (**Fig. 3A**). However, they do feel that EGR150 has helped them to increase their understanding of vector math and understanding of general PHY160 content (**Fig. 3B, C**), with slightly higher gains in the >90 category (vectors: 8.42±1.22 and general content:7.61 ±1.65, $n = 9$) versus the <70 category (vectors: 5.17±2.48 and general content:5.67 ±2.35, $n=3$). Students are rating the helpfulness of the problem-solving method above five in all groups except the 80-90 category (**Fig. 3D**). This may be because many of them feel that the method is tedious and the time it takes to complete it outweighs possibly benefits [14].

Regardless of how our students are integrating the content between the two courses most students recommend at an average of 4.19/5 for continuing to incorporate the use of PHY160 based problems into EGR150, likely indicating that repetition of the topics and concepts alone is helpful.

Based on PHY160 grades, the >90 category responded more favorably than the <70 category by about 20%.

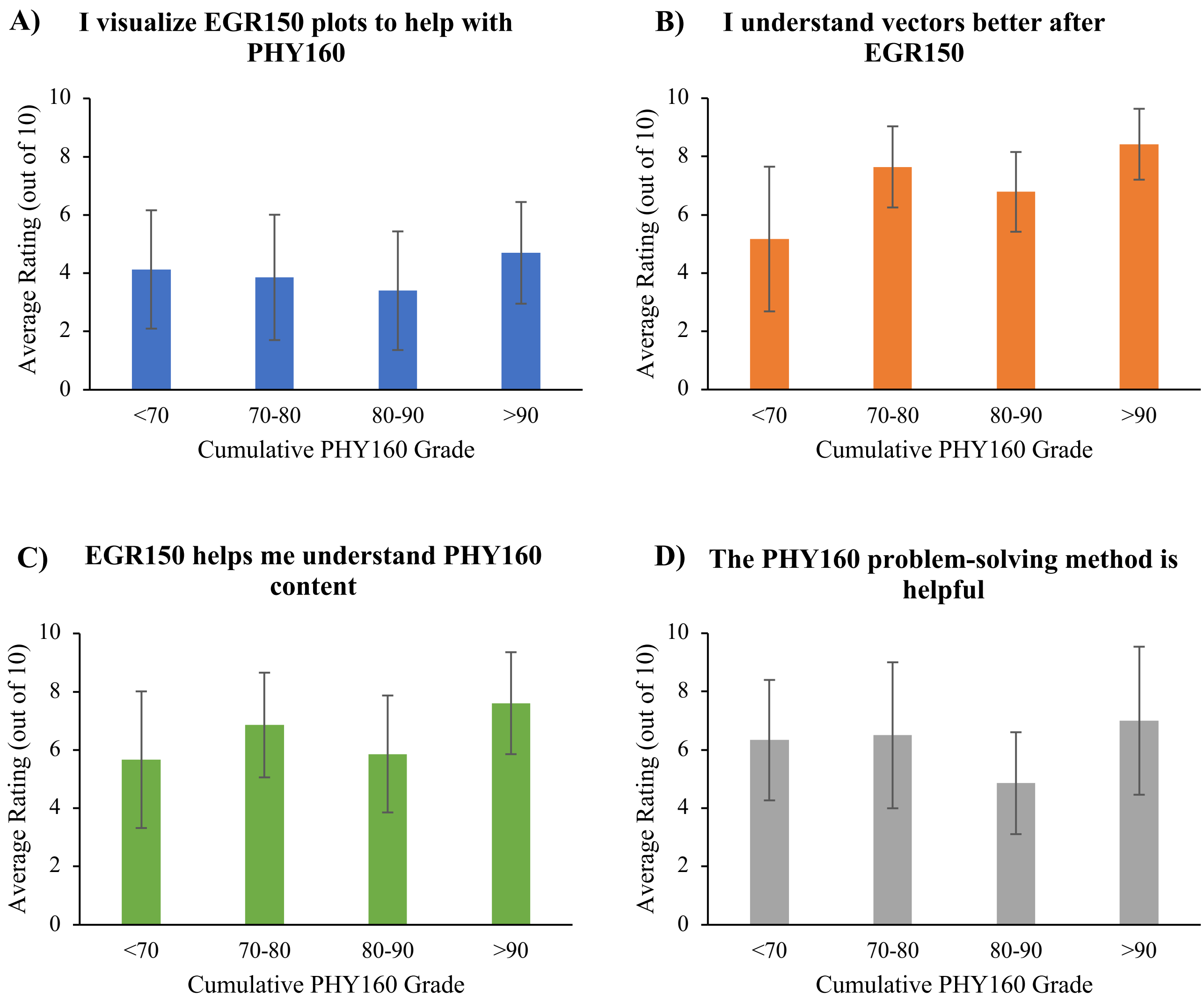

Figure 3. Student survey responses indicate that **A)** students are not visualizing the graphical outputs in MATLAB to help them think about concepts or solve problems in PHY160. **B)** Most students understand vectors better after EGR150, with slightly higher gains in the passing students comparing to failing students. **C)** All students are roughly neutral in their feelings toward whether EGR150 helps them in PHY160. **D)** Most students find the problem-solving strategy at least somewhat helpful.

Faculty Observations

Our results indicate that students are benefiting from the repetition of PHY160 material in EGR150 even if they can not explicitly articulate how they are using the added exposure to improve their understanding. Previous work has shown that repetition sharply increases recall with technical topics [16]. Burr [17] related the Half-Life Regression (HLR) of student retention to learning new languages and would apply to learning a "scientific" language such as problem-solving or MATLAB as well. Nonetheless, there are numerous studies that have concluded that repetition and exposure to a topic, concept, or technique benefits students. Therefore, the approach here represents a specific application of repetition and integration across the curriculum to mitigate failing grades in PHY160, a course with a high failing rate at many institutions. Since only three failing students took the survey, it is difficult to draw strong conclusion. The PHY160 courses was redone to enhance the active learning strategies and amount of practice a number of years ago, which already reduced the percent of failing students from 50% to 10% [11,12,14]. It is likely that trying to make a major change in that remaining 10% will be challenging. However, the overall positive response indicates that by improving the timing of the Physics problems in EGR150 we could enhance the learning outcomes as that was noted not only in the Likert Scale responses but also in numerous comments. Additionally, it's interesting that the 70-80 category was responding more similarly to the >90 category in the survey (**Fig. 3B-D**), possibly indicating that they are employing more expert-level thought patterns that are keeping them in at a passing grade.

Some students indicated that they view the inclusion of PHY160 problems as extra work, "While I appreciate the thought to add physics problems, my physics class already overloads me with work on Wiley and written out where I don't feel that problems in other classes are necessary." The reality is that these new problems were not in addition to the normal problem set in EGR150, but rather they replace the problems that had been used prior from Gilat [15] that had no relationship to the ongoing PHY160. Beyond this, in our first semester using these techniques (Spring 2020) ~15% of the students had already taken PHY160 in a previous semester and didn't find the incorporation of these problems to be very applicable. As educators, we feel that continuing to reinforce fundamental Physics knowledge as the basis for all engineering is useful to all students, even if they are not currently enrolled in PHY160, but especially if they are.

It could also be argued that coordinating class materials across curriculums leads to a lack of diversity in the overall program. At most schools, full time faculty and adjunct may teach topics completely differently using different textbooks. However, most schools have simple descriptions for the topic being covered touching on some of the topics that will be learned during the class. Moreover, academies like U.S. Military Academy (USMA) and The U.S. Naval Academy (USNA) teach several topics like physics and calculus that are made more or less uniform across the cadet/midshipmen curriculum. Given the excellent ranking these institutions have would seem to indicate that this is not a drawback to the learning process.

Conclusions

Moving forward we will expand our student survey and improve the coordination of problem assignments throughout the semester. It will be equally important to spend a little extra time in the coming semester explaining the rational of the approach and making clear that these are not additional work, rather replacing unrelated practice that would have been given from *Gilat* [13]. Placing additional emphasis on the problem-solving approach being the same whether you find the final solution by hand or with MATLAB would also benefit the students who are struggling to see the processes as similar.

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Appendix A: Student Survey

Do not put your name on the paper – this should be completely anonymous!

Please answer the following questions about your experience in Physics Mechanics (PHY160) and Computational Methods (EGR130). We are trying to understand the impact of adding targeted Physics problems to Computational Methods on helping you gain a deeper understanding of Physics concepts and problem solving.

1. **What is your current cumulative percent grade in Physics? (Circle a score range)**

<30% 30-50% 50-60% 60-70% 70-80% 80-90% >90%

2. **What percentage did you get on the first Physics test of the semester? (Circle a score range)**

<30% 30-50% 50-60% 60-70% 70-80% 80-90% >90%

3. **What percentage did you get on the second Physics test of the semester? (Circle a score range)**

<30% 30-50% 50-60% 60-70% 70-80% 80-90% >90%

4. **How correlated do you feel the Computational Methods Physics problems are to the material you are learning in Physics? (Circle one number)**

Not correlated at all Neutral Perfectly correlated

1 2 3 4 5

5. **The physics problems in Computational Methods are approached using the same problem-solving method as in that is used in Physics?**

Completely different Neutral Completely the same

1 2 3 4 5

Describe how well the following statements describe you and your response to physics and/or computational methods on the scale of does not describe me at all (1) to perfectly describes me (10).

6. **I frequently visualize the output graphs of physics problems from computational methods when thinking about a physics concept.**

Does not describe me *Neutral* *Perfectly describes me*

1 2 3 4 5 6 7 8 9 10

7. **I never visualize output graphs of physics problems from computational methods when taking physics exams.**

1 2 3 4 5 6 7 8 9 10

8. **I understand vectors in physics better after using them in computational methods.**

1 2 3 4 5 6 7 8 9 10

9. **I don't feel that the use of Physics problems in Computational Methods helps me to learn and remember physics.**

1 2 3 4 5 6 7 8 9 10

10. **Having a chance to create graphs from equations of motion in computational methods helps physics "click" for me.**

1 2 3 4 5 6 7 8 9 10

11. **I'm still really confused on vectors despite covering them in computational method and physics.**

1 2 3 4 5 6 7 8 9 10

12. **I feel that the problem-solving methodology (Given, Find, Assumption, Estimate, Plan, Solution, Reflection) is useful and helps me get the right answers when solving Physics Problems.**

1 2 3 4 5 6 7 8 9 10

13. **I use MATLAB to help me check my answers from physics problems when I'm unsure of my math.**

1 2 3 4 5 6 7 8 9 10

14. **When taking a physics test, I often think back to computational methods problems to help me visualize concepts and mathematical solutions.**

1 2 3 4 5 6 7 8 9 10

15. **I feel that the problem-solving methodology (Given, Find, Assumption, Estimate, Plan, Solution, Reflection) is tedious and unhelpful.**

1 2 3 4 5 6 7 8 9 10

16. **I think having exposure to Physics concepts in multiple classes improves my understanding of Physics.**

1 2 3 4 5 6 7 8 9 10

17. **Do you think the integration of Physics problems into Computational Methods should continue for future semesters?**

Definitely Not Neutral Absolutely Should

1 2 3 4 5