Homework by choice:
STEM-Focused and Personalized for First-Term Calculus Students

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Abstract: In this project we seek to improve success and retention of STEM majors by improving student motivation for problem solving in STEM applications. This is done through enhancing first year and second year Calculus courses by not only connecting the learned theory to real-life STEM examples, but moreover relating them to the students' actual areas of interest. Many projects and assignments were designed for this purpose, with a basic structure of (a) watching a video with examples, (b) choosing an area of interest, (c) solving a real-life application based on this choice, and (d) filling out a short survey and discussing with peers. We believe that this project is an extension of previous results that show the positive effect of homework on student learning, with the added motivation that comes from the student's personal interest.

Keywords: STEM, Education, Interdisciplinary, Engagement, Calculus

Many of the real-life challenges we face today, such as health, transportation, resource management, energy shortages, overpopulation, and climate change are integrated problems that involve more than a single discipline. Kennedy and Odell (2014) observe, "STEM education has evolved into a meta-discipline, an integrated effort that removes the traditional barriers between these subjects, and instead focuses on innovation and the applied process of designing solutions to complex contextual problems using current tools and technologies" (p. 246). One of the core tools of STEM disciplines is Calculus since many of the problem-solving techniques across STEM fields are based on calculus. A principal challenge is that the mastery of calculus concepts requires a high level of rigor and engagement in delivery, as well as motivation on the students' part.

Students of STEM disciplines face a lot of challenges, such as rigor, cost, being in an underrepresented group. Furthermore, educators and teachers of STEM disciplines face their fair share of challenges. Teaching multi-disciplinary courses, in particular, the first term and second term Calculus courses, instructors must aim to balance several teaching elements including:

- Delivery of concepts and theory.
- Connecting the theory to real-life STEM examples, assignments, and projects.
- Relating the STEM projects to the students' areas of interest.

- Reinforcing the basic concepts and theory.
- Engaging the students and keeping them involved and invested in the learning process.
- Introducing students to several disciplines so that they can find their areas of interest.
- Allowing the students to feel a sense of control in terms of which problem to tackle, which will boost their morale and encourage them further.

Following the saying "success is a great motivator," homework is often used as a motivating tool in addition to a training tool. Well-designed homework builds students' confidence by guiding them through achieving sequential successes, which gives them a sense of wanting to achieve more. Many studies have shown the positive effect of homework on student learning in mathematics courses (e.g., Cartridge and Sasser, 1981; Halcrow and Dunnigan, 2012; Kitsantas et al., 2011). Moreover, it was shown in Halcrow and Dunnigan (2012), that online homework can be just as effective as written homework in promoting student achievement.

Homework can be effective not only to motivate and train students, as mentioned above, but also as a means for students to gain experience with deeper application problems. As class is usually designated for basic principles and examples, and homework allows the students to take a deeper dive into applications of these concepts. However, Horwitz and Ebrahimpour (2002) observe that introducing STEM projects from several disciplines to all the students did not achieve the desired goal of motivating the students to desire a deeper understanding of calculus. This study provides valuable insights into the potential limitations of STEM projects in motivating students to desire a deeper understanding of calculus. These findings can inform educators today in designing effective pedagogical strategies that encourage and motivate students to engage with mathematical concepts.

While it's true that the field of teaching has evolved over the past few decades, the foundational principles of learning remain largely unchanged. These principles are still relevant in today's context, as many schools and universities continue to assign homework and leverage technology for online learning. Furthermore, the importance of practice and deeper learning through application problems continues to be a key learning activity, particularly in mathematics.

In this work, we designed several projects and assignments for the first-term Calculus students to address the practice of foundational concepts. These assignments were designed by the authors after researching applications of the selected disciplines. In these assignments, the students will have to go through multiple learning activities:

I. Reinforcement of concepts and theory: Watch a short video with examples.
II. Relate or explore: Choose an area of interest (Computer Science, Data Science/Business Analytics, Mechanical Engineering/Physics/Science or Electrical/Computer Engineering). At this stage, students can select an application that they can relate to or explore a new application that they have not seen before.
III. Connect the theory to real-life: Solve a real-life application problem covering the concept within the area or interest chosen in the previous stage.
IV. Provide Feedback: Fill out a short survey.

In the short survey, students were asked to describe their level of interest, relay their feelings about the application, and whether it was helpful for them to relate the concept to an example from their intended major.

Finally, at the end of the term, the students filled out a more extensive survey and gave their overall impression of the homework system.

Background

There are many studies and surveys attempting to determine the factors influencing STEM education. In 2019, a White House report suggested that only 20% of high school graduates are ready for the rigors of STEM majors (Herman, 2019). The report mentions that over the past 15 years, the United States has only produced 10% of the world's science and engineering graduates. Furthermore, students enrolled in STEM programs change their majors at a very high rate. According to a 2013 report by the National Center for Education Statistics (NCES), 48% of bachelor's degree students and 69% of associate degree students who entered STEM fields between 2003 and 2009 had left these fields by Spring of 2009 (Chen and Soldner, 2013). Another study found that fewer than 40% of students enrolled in STEM receive their degree in STEM (Chen et al., 2018). The same study found that there are a host of reasons for these percentages, such as the lack of financial support in some instances, and social and family reasons in others.

Many of the reasons that may drive a student to leave a STEM program are out of the control of the faculty. However, one of the primary reasons why students switch out of STEM majors is the presumed difficulty level and rigorousness. Yet, an observation in Kricorian et al. (2020) listed that 73% of respondents demonstrated growth mindsets: they agreed that with the right amount of effort and dedication, anyone can become a top scholar in STEM. In fact, it was shown in Gasiewski et al. (2012) that engagement methods have proven useful to catch students that are on the edge and may drop out or switch out of a STEM program.

The students' engagement consists of effort, attention, and participation during learning activities. In addition, they must have interest and feel enjoyment. This is by no means an easy task because most real-life problems require an integrated STEM (iSTEM) approach to solve. Connecting ideas from different disciplines is difficult, especially for students who have yet to gain a small level of understanding of the relevant ideas in their own disciplines. Hence, students will need to be guided to find the mathematical concepts and engineering design ideas that will be relevant and then connect them together to solve the problem (Kelley and Knowles, 2016).

In one study, calculus students were asked to complete assignment modules with real-world engineering problems outside of class and discuss them in mentor-led sessions. The results of the study show that the majority of students also found that the modules better prepared them for success in calculus. Moreover, the engineering content was useful in helping students feel connected to engineering (Neubert et al., 2014). However, not all calculus students are engineering majors. In fact, one way to keep students more engaged in math may be to tailor the real-life applications that they see to their majors or academic interests.

Student interest as related to learning has been the subject of a number of studies over the years. Personalized reading passages have been shown to be successful in increasing motivation and engagement in elementary school students (e.g., Cordova and Lepper, 1996; Hellman et al., 2010). In another study, students were taught a theoretical principle. The students who were able to choose the subject of an example related to the principle showed more interest in the topic than students who were not given the choice (Reber et al., 2009). Similar results of the effect of personalization on student interest was studied in mathematics in high school algebra students (Walkington, 2013, Walkington and Bernacki, 2019) and middle school students (Hogheim and Reber, 2015), but to the authors' knowledge, this study is the first instance of studying the effects of personalizing student work in a college Calculus course.

The New Homework Solution

The authors designed seven primary sets of problems, which target several key points we believe essential to students' success. Focusing on the four learning activities previously mentioned in the introduction, each problem set has five different variations of the same question covering applications from four disciplines: Mechanical Engineering and Physics/Science, Electrical and Computer Engineering, Data Science and Business Analytics, and Computer Science. The choice of disciplines allows the students to have a sense of control of the topics that best suits them. Also, the disciplines were selected to serve the current degree offerings at the authors' institution. Finally, the last variation is a generic problem with no specific application.

Description of Projects and their motivation

Next, we will present projects and students' results, as well as some of the students' responses to the surveys and our analysis of their responses.

Functions. Many students start their academic careers in the fall semester after a long summer break and they are expected to hit the ground running in Calculus 1. This usually frustrates the students, and many of them find it difficult to balance getting used to the pace, college life, and the high demands of the course. This assignment has been designed to review one of the concepts covered in the prerequisite courses and help set the tone and motivate the students.

Limits. Limits are a key point in understanding all of Calculus. However, the students have always struggled to understand the meaning of the term *approach*, and the concept of when two quantities are close to each other. In particular, students have difficulty understanding infinite limits and treat the infinity symbol as a fixed, large constant. The problem set on limits is meant to put into perspective how infinite limits play a role in real-life applications. The assignment focuses on understanding the eventual behavior of functions.

Average Rates of Change. Determining the average rate of change of a function using data tables or graphs is the key to understanding derivatives and behavior of functions. Students favor memorizing rules and procedures which are formula driven. This project is meant to show students those functions can be represented using other means, and students can still investigate their behavior.

Exponential Models. The exponential function and its rate of change are incredibly useful in many real-life models, and the students seem to have a good grasp of the mechanical skills such as differentiating and evaluating due to their good performance in the traditional computational exercises. However, there is still a need for them to see more realistic models that use exponential functions in addition to the simplified examples that most textbooks have.

Linearization. This is a heavily applied and important concept that students need to master. However, they have trouble using linearization to approximate functions locally. This is largely because linearization is introduced in most calculus books as a purely mathematical and computational process, and the examples provided are over simplified. This problem set presents the students with context that they can relate to and offer intuition on how linear approximation is used.

Extrema. Finding local and global maximum and minimum values of functions is widely used in common real-life problems. Based on observation, students have had moderate to high level of success in Calculus courses finding these extrema but only as a process. Students still struggle to put these techniques into the context of real applications as reported by several faculty members teaching the advanced discipline specific courses.

Integrals. Students are usually introduced to integrals as the limit of the Riemann sum used to calculate the area between a basic curve of a function given by $y = f(x)$ as x varies over an interval $[a,b]$. However, this is just the tip of the iceberg. Usually, at this point, which is towards the end of the first semester Calculus course, the students are struggling to keep up and are feeling the pressure that causes most of them to simply memorize integration formulas as opposed to understanding the concept.

The Homework Assignments

This project attempts to keep the students engaged and attentive in order to rekindle their interests. An experiment was run where some students (test group) were given the projects listed above while another set of students (control group) was assigned generic projects. In each set of problems, the questions were carefully picked to be as similar in level as possible with only the context differing based on the choice made.

The schematic for the 'Exponential Models' assignment is shown in Fig. 1, and the problems by discipline for this assignment in Fig. 2. These assignments were built using the H5P platform, which is a web-based tool that allows for interactive videos and assignments.

Figure 1

Schematic of branching scenario for the exponential modeling assignment. Students explore either from left to right i) neutron attenuation (Mechanical Eng./Physics/Science), ii) diodes in electrical circuits (Electrical Eng./Computer Eng.), iii) passcode complexity (Comp. Sci.) or iv) demand (Data Science/Business Analytics).

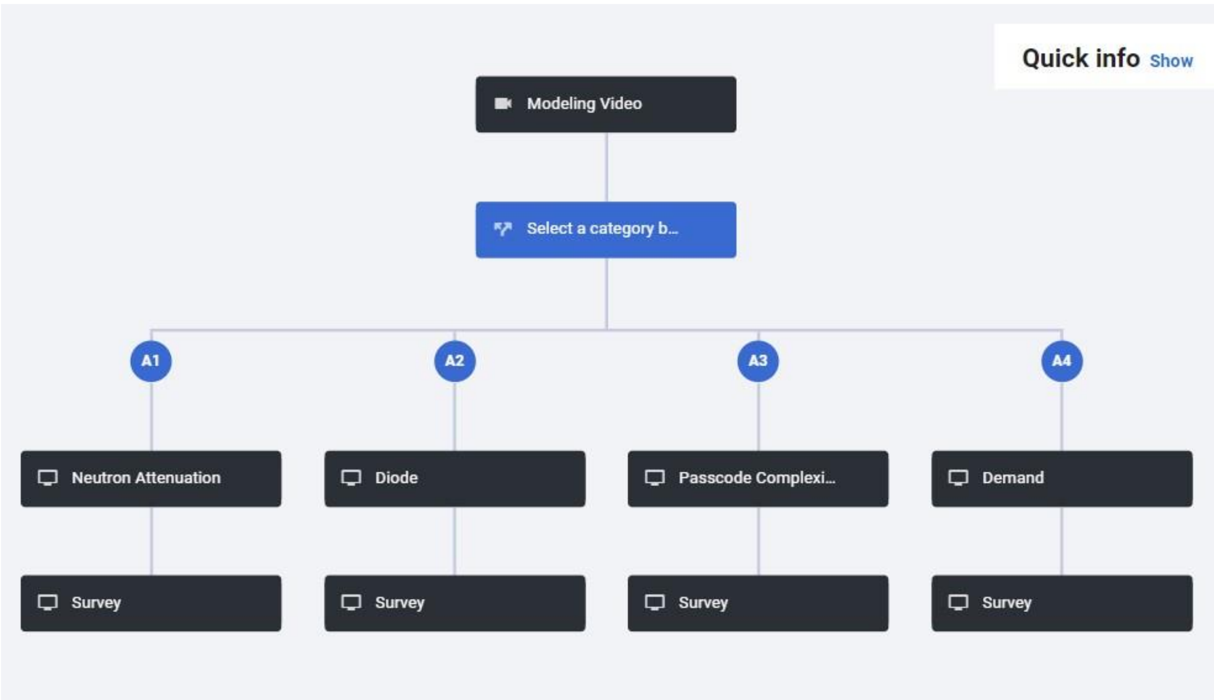
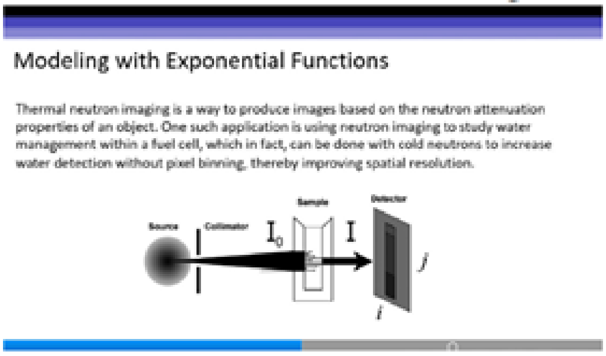
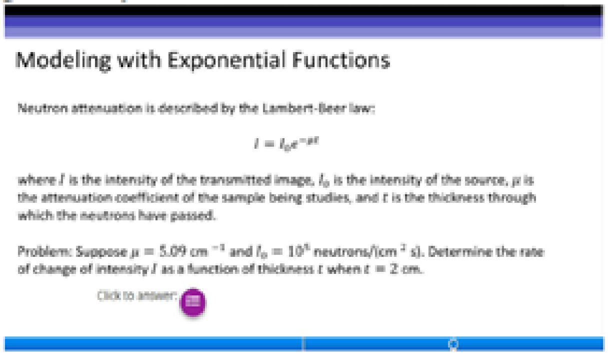


Figure 2

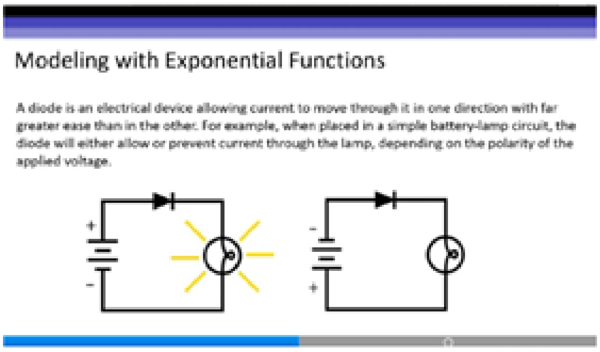
Example exponential modeling problems for different discipline selections.

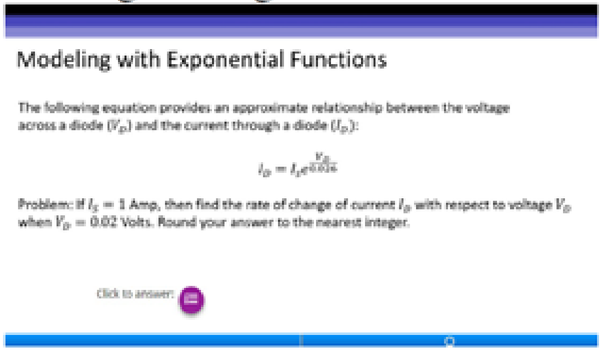
Mechanical Engineering & Physics/Science:



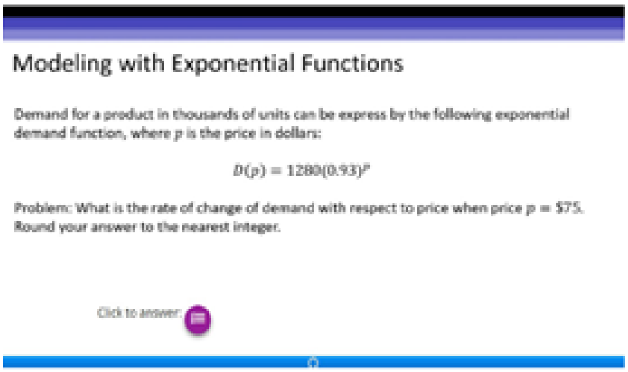


Electrical & Computer Engineering:

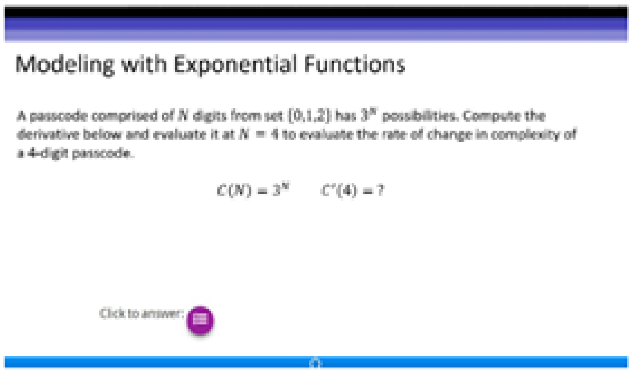




Data Science & Business Analytics:



Computer Science:



Results

Homework Scores

A total of 140 students took the survey, with 76 students in the experiment group and 64 students in the control group. Table 1 shows a brief statistical summary for some of the students' results on five of the projects during the Fall 2021 semester. The projects here are listed in the order that the students were asked to work on them. All the problems were graded automatically for instantaneous feedback, and the scores were scaled to be out of 100. The students' performance improved as we progressed in the semester.

Table 1

Statistical summary of students' scores out of 100 points during Fall 2021

	Functions	*Limits*	*Linearization*	*Extrema*	*Integration*
Mean	79.82	82.55	83.27	89.47	93.35
Median	66.70	83.30	100.00	100.00	100.00
Std. Deviation	16.40	16.81	19.08	16.02	13.91
Range	33.30	66.70	60.00	66.70	50.00
Minimum	66.70	33.30	40.00	33.30	50.00
Maximum	100.00	100.00	100.00	100.00	100.00
Count	66.00	62.00	50.00	83.00	49.00

Surveys

Students generally gave thoughtful answers to the survey. Many were positive, while many had valid criticisms. The positive comments included the following:

- "It was engaging to have homework that related with my major."
- "The H5P were interesting and insightful specially to engineering applications using calculus."
- "The H5P assignments were a nice addition to the course as they provided context for how calculus can be used in a person's major."
- "In regard to question 8, I wouldn't suggest H5P be the only given homework assignments. They should be coupled with other homework similar to this year except potentially have more of them."
- "The video examples shown before the H5P homework problems helped in understanding the material."

These comments suggest that incorporating practical applications of course material, such as H5P assignments and video examples, can enhance students' interest and understanding of the subject matter, especially when it relates to their major. However, it is also important to balance the use of such assignments with other types of homework to provide a well-rounded learning experience.

The critical comments included the following:

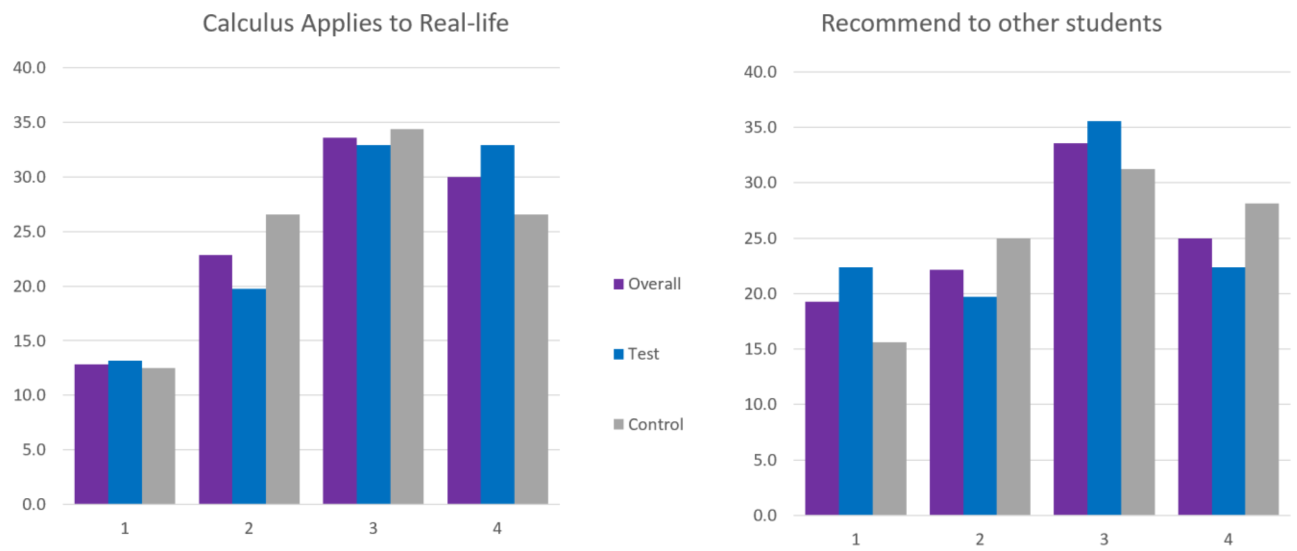
- "Make the 4 categories work a similar difficulty. I sometimes went into the one I was majored in, found that really hard, backed out and then went into a different one that was just easier."
- "The videos should be more tailored towards the question."
- "There were a few where the questions seemed like quite a step past the examples given, but not too drastic."

The critical student comments suggest that there are areas of the assignments that could be improved to optimize the effectiveness of the learning experience. Specially, the perceived level of difficulty across different categories of work should be consistent, and videos that target the applications of the concepts rather than being a reminder of the concepts. These critiques offer valuable insights that can be used to enhance the quality and effectiveness of the course material.

In addition, 60% of the students found the difficulty level reasonable and almost the same percentage agreed that Calculus applies in many areas of our everyday life, (Fig. 3). About half the students felt that the problems were interesting. Also, over half believed that these projects were worthwhile additions to the course and would like to see similar projects in other courses. Furthermore, about 60% of the students also would strongly recommend a course with these kinds of projects to their colleagues (Fig. 3). More than 70% of the students (over 80% from the control) agreed that these projects were very helpful to understand the content.

Figure 3

Sample of Students' rating 1 (strongly disagree) to 4 (strongly agree)



Conclusions and Future Work

In conclusion, this study presents the preliminary results from a new approach to homework assignments for first term Calculus students in STEM-focused majors. The assignments were designed to target several aspects that are known to help students be more successful not only in their first Calculus course, but in all their STEM education and beyond. The homework assignments focused on reinforcement, relatability, exploration, and connecting the theory to real-world applications. While some students' comments indicated that they were resistant to the new types of assignments, and favored more of the traditional type of homework from a textbook as was familiar to them from high school, the majority of the students felt that they benefited from focusing on applications that are more relevant to their majors as opposed to generic applications and homework. The control group also commented that they benefited from the reinforcement videos and found the problems interesting even though they were not given a choice of the type of problems they were assigned.

While the authors believe the methodology was valid and useful to the students, there is room for improvement in the variety of applications, frequency, and consistency of projects. During this Spring 2022 semester, we added two more projects, improved our survey to gather better data, and are helping the students communicate their thoughts and opinions to the authors more efficiently. Moreover, noting the Count variation in Table 1, the authors plan to switch from attaching the projects along with the regular homework to administering the projects in class to obtain better consistency in student participation. We are planning to expand this project to other courses such as Precalculus and the second-term Calculus courses. In doing so, we aim to improve the retention and overall success of all students in STEM focused majors.

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