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Reinforcement of Computer Programming through Projects

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Abstract

Computer programming is an integral part of being an engineer and has provided a means of performing analysis that would be cumbersome to complete analytically. In Fall 2022, a set of projects were developed for a junior level dynamics course. In prior offerings of this course, the typical dynamics theory was covered and assessed using textbook assigned problems and exams. The developed projects required the students to recollect their knowledge of MATLAB programing from their programming class taught during their first year and apply those skills to solve systems over a specified time instance. In this paper, the three projects developed are presented. Subsequently, the assessment of the students' performance with respect to the desired learning outcomes is presented. In addition, a discussion of the results is presented coupled with the post survey results from the students. Lastly, lessons learning from the projects along with recommended future improvements are presented.

Introduction

With advances in technology and a heavier use of computers in industrial settings, it has been observed that programming is a necessary skill for all engineering majors to develop. In addition, to knowing the basic programming skills it is imperative that students graduate with the ability to utilize programming tools to solve complex engineering problems.

In the mechanical engineering curriculum, dynamics is a critical course that all students must take and it focuses on the analysis of objects in motion when acted upon by external forces. Dynamics has two primary areas kinematics and kinetics. Kinematics is the analysis of motion in an object and kinetics is the analysis of forces in objects in motion. When performing either analysis it is important to develop a set of equations that model the motion and/or forces over time. For this reason, programming projects can be easily implemented in the course to allow for calculations over time to occur. This all is based on the assumption that students have prior experience with the program being used.

In this work, a set of three projects are developed. These three projects require the students to construct a computer program in MATLAB to find a complete solution. When designing the projects, the following learning outcomes for the students are desired. First, students will be able to transform dynamics modeling equations into a properly structured MATLAB program. Second, students will be able to rationalize dynamics equations as functions of time which can be modeled in MATLAB to create plots that allow for visualization of the data.

This paper is organized as follows. First background in the area of programming project integration into a curriculum is presented. Next, the development of the course projects is presented. This section includes the explanation of the project style and an explanation of the desired learning outcomes for each project. Next the resulting outcome from the conducted projects along with a discussion of the implementation is provided. Following the discussion, future improvements to the projects will be covered along with concluding remarks.

Background

The idea of implementing programming projects in engineering courses is not novel. In recent years the number of projects involving the use of programming software such has MATLAB has rapidly grown. This growth in the mechanical engineering field has occurred for two reasons: 1) it helps provide students with more exposure to programing which is desired skill in industry and 2) allows instructors to assign problems that would otherwise be cumbersome to solve by hand.

When designing an engineering curriculum, it is important to consider problems and projects to incorporate concepts from Problem-Based Learning (PBL) and Project-Based Learning (PjBL). PBL should be used in the classroom because it has been shown to deepen students' critical thinking, increase student interest in their area of study, and increase students problem-solving skills [1, 2, 3]. PjBL is an instructional method that aids students in deeper learning and development of non-cognitive skills that are necessary for their future career [4]. The main issue with these two instructional methods is that it can present significant challenges for students that are under-prepared or are not provided adequate resources (*e.g.*, instructor office hours or tutors) [5,6]. A variety of PBL and PjBL methods utilize programming software such as MATLAB to allow students to simulate their model and various conditions.

At the Virginia Military Institute (VMI) Dynamics has always been taught in the traditional fashion where students are taught kinematics (the modeling of motion of an object) of particles and rigid bodies and then kinetics (the modeling of the relationship between loads and motion) of particles and rigid bodies. Following these two classical mechanics divisions the students are taught energy based methods. While teaching these concepts students are provided textbook problem sets in addition to three semester exams and a comprehensive final exam. While these are all necessary and helpful educational tools they miss assessing a student's ability to apply the knowledge to an open-ended problem. In addition, for dynamics, these limited problem sets do not provide students with exposure to looking at a mechanism throughout the range of motion. Instead, students only analyze a mechanism at a single instance in time.

A reason, this portion of the education has been missing from the class is the complexity of solving an open-ended problem by hand due to the numerous substitutions that may be required. However, when a programming tool like MATLAB is used properly it allows the students to focus more on the development of the modeling equations an utilize MATLAB to perform the substitutions and solve for the unknown values. The second feature that MATLAB provides is the ability for students to simulate their model over time to observe the results over the full range of motion for a mechanism.

Project Development

During the semester three separate projects were implemented. For each project the students were broken up into two-three person groups. The details of each project is provided below.

Mini-Project 1

The first mini-project focused on the topic of kinematic analysis of particles. The goal of this project was to analyze two cars going around the track shown in Fig. 1. One car had a faster acceleration/deceleration rate then the other car, but had a slower top speed. With these parameters the students had the intuition that the car with a higher acceleration limit would catch up or extend the lead in corners but was likely to lose the lead in the straight stretches. The students were tasked with analyzing the motion of both cars completing a single lap around the track and the relative position between the cars to determine which one would complete a lap faster and by how much time/distance.

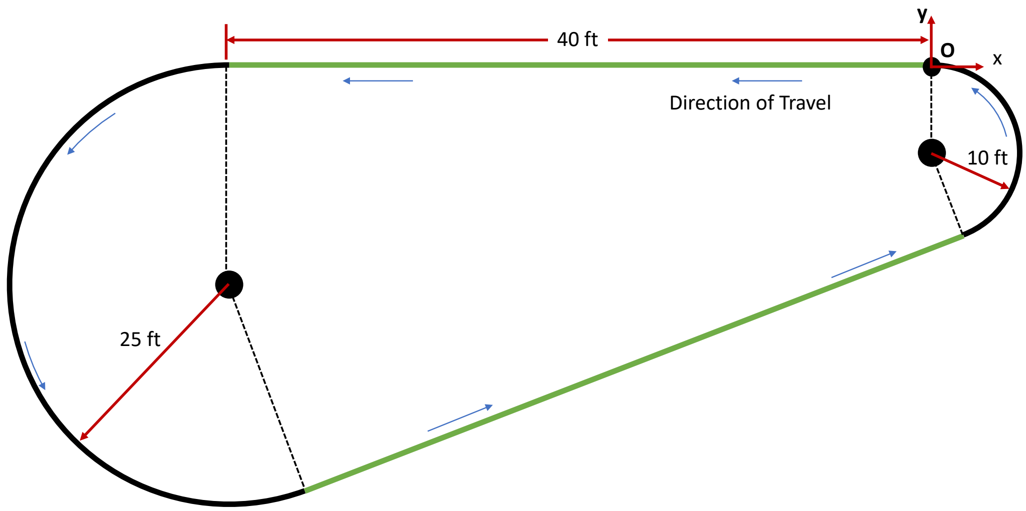


Figure 1. Track for the cars to complete.

As mentioned before, for the two cars the students were provided maximum lateral and longitudinal accelerations that each car was capable of achieving through a G-G diagram as shown in Fig. 2. The reason, the G-G diagrams were used in this project were because a G-G diagram is a standard plot for showing the dynamic performance of a car because it displays both forward (acceleration and braking) forward along with turning performance. In Fig. 2 the blue ovals indicate the maximum performance of the car. This means that each car can experience a longitudinal-lateral acceleration value anywhere inside the oval but peak performance occurs on the oval and the car cannot achieve an acceleration value outside of the oval because it is will result in the car spinning out/losing control.

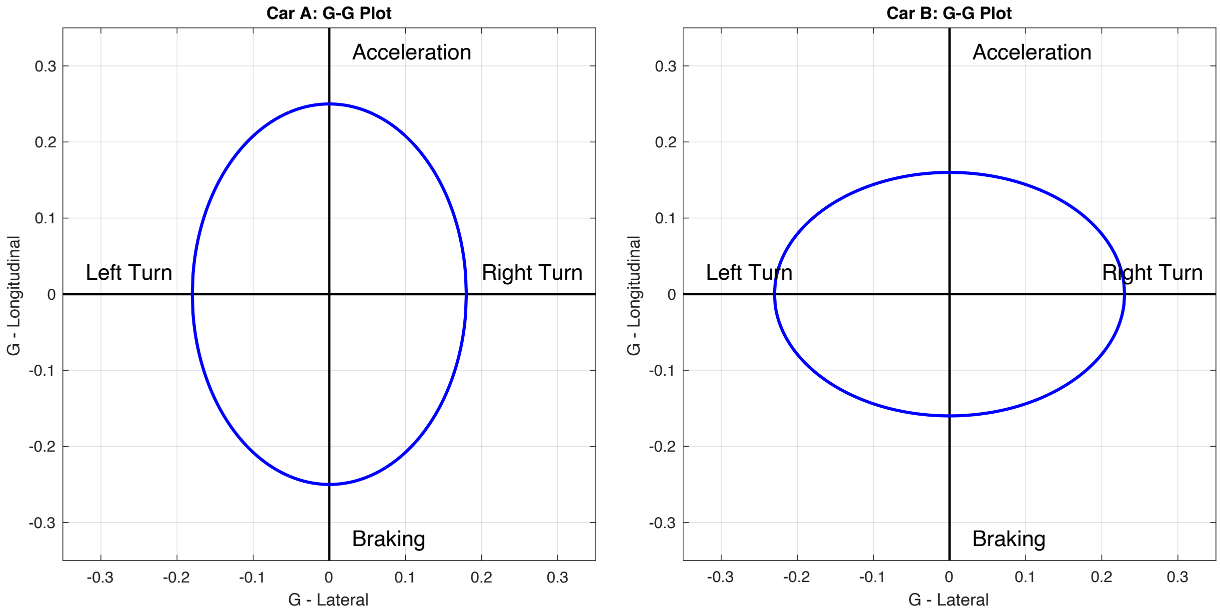
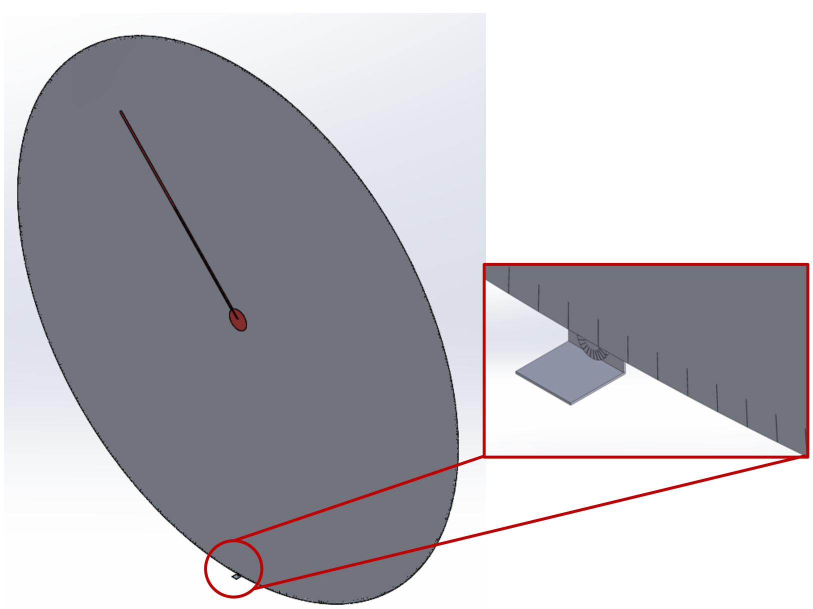


Figure 2. G-G plot for Car A and Car B.

Mini-Project 2

The second mini-project focused on the topic of kinematic analysis of rigid bodies. The goal of this project was to design of a count-down clock utilizing a Geneva mechanism. The students were given that the Geneva mechanism would be driven by an electric motor with a programable constant angular velocity up to 64 rpm. The Geneva mechanism needed to have two wheels, one that would complete a single revolution each day and one wheel that would complete a single revolution by the time the students would graduate, 568 days away. An example Geneva mechanism that achieves these goals is provided in Figure 3.



Figures 3. Example Geneva mechanism design for the countdown clock.

When designing the Geneva mechanism, the students needed to perform a kinematic analysis of the pin on the driving disk that is in contact with a slot in the driven disk. The kinematic analysis was used to ensure the spacing between the disks was sufficient to match the velocity direction of the pin with the direct of the slot. By having these directions match up the Geneva mechanism would spin smoothly and not over-rotate after the pin moves out of the slot. This kinematic analysis provided the students with experience analyzing the relative motion between two rigid bodies.

The students utilized MATLAB to aid in the design of the lengths for the Geneva mechanism disks and mounting locations. After determining the design of the Geneva mechanism, the students used MATLAB to simulate the motion of the Geneva mechanism over time to ensure the daily disk made a rotation every 24 hours and the graduate disk made only 1 rotation after 568 days. In addition, while performing the simulation over time the students were able to see that the results from their kinematic analysis showed an intermittent motion of the driven disk that correctly models what is happening when the pin of the drive disk comes in and out of contact with the driven disk.

Mini-Project 3

The third mini-project was based around the topic of kinetic analysis of rigid bodies. The project focused on the analysis of the trampoline fatigue testing rig in Fig. 4 throughout the full range of motion of the machine. Throughout this range of motion, the students needed to find the forces at the connecting points B and C along with the torque that would be needed to drive the main disk. During the process of analyzing these forces, the students would need to find the range of motion where the feet (Point D) are not in contact with the trampoline and the range where they are to determine when a trampoline spring force should be included.

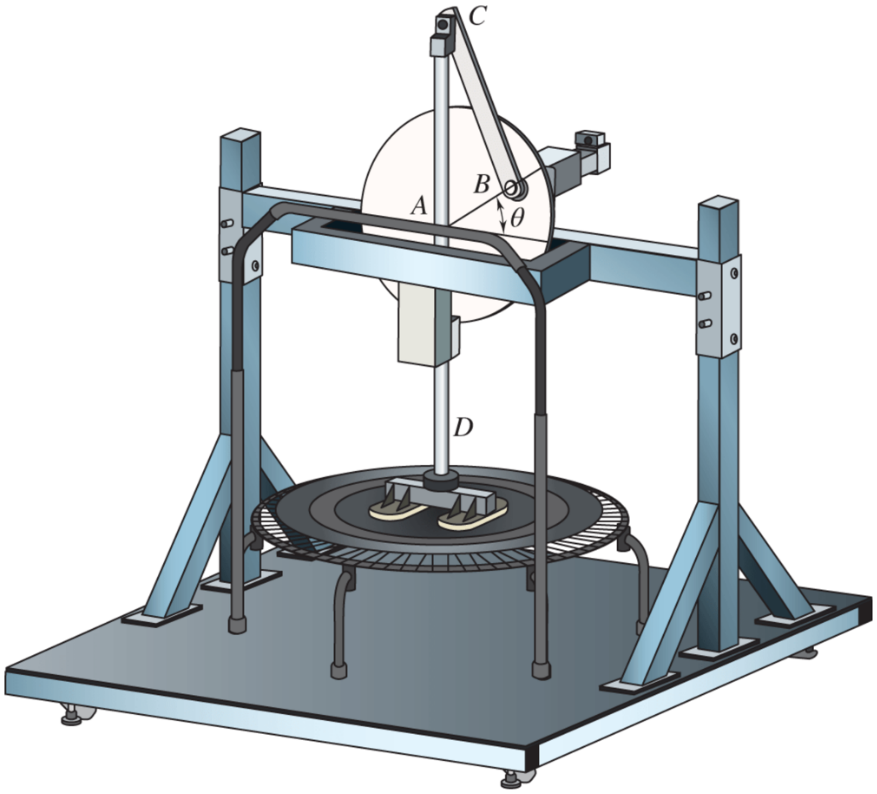


Figure 4. Representation of the trampoline testing rig [7].

To solve this problem the students had to separate out individual rigid bodies and define the kinematic and kinetic equations necessary to analyze the motion and forces through the bodies. Then, using MATLAB they were able to solve the coupled equations at all angles of the driving disk and generate plots of the resulting forces as a function of the input disk angle θ.

Assessment of Programming Improvements

Throughout the three mini-projects I observed an improvement in students' ability to use MATLAB to solve engineering problems. These observations were based on my interactions with the students on a daily basis and on their ability to apply MATLAB in previous course work (i.e., Statics and Solid Mechanics). When teaching this cohort of students Statics and Solid Mechanics the previous year I found that they had trouble converting their statics models into a logical format that MATLAB could solve. Thus, during the dynamics mini-projects I observed that as the semester progressed they more easily were able to think through solving the projects logically and transform the dynamics models into a proper MATLAB structure. These observations were supported by the students' questions that I was asked. At the start of the semester students asked more questions related to MATLAB structure, whereas at the end of the semester they were asking more questions on how to streamline their MATLAB code and perform more advanced features that were not covered in class.

To assess the students at the end of the semester I completed our ABET course assessment and referenced two of our learning outcome assessments. The first assessment measures the following learning outcome: "Able to use general engineering analytical software, such as MATLAB, as a tool for solution of common engineering problems". The rubric used to assess this learning outcome is provided in Table 1. The second assessment measures the following learning outcome: "Able to develop appropriate software program to solve a mechanical or thermal engineering problem". The rubric used to assess this learning outcome is provided in Table 2. At the end of the semester my assessment was that the Dynamics class scored a 4 for both the general MATLAB use and application of MATLAB categories. A score of 5 for the general MATLB use was not awarded because I observed that full validation of the results was not performed. A score of 5 for the application of MATLAB assessment was not awarded because I observed that the students had difficulty at time choosing if a loop was necessary or if a function or subroutine could be used.

To provide comparison to this assessment in the previous academic year I taught this class of students Statics in the fall semester and Solid Mechanics in the spring semester. In both of these classes the students complete a group design project that features the use of MATLAB. In those classes I assessed the students as having a general MATLAB use score of 3-4 depending on the course section and a MATLAB application score of 2-3. Comparing these scores to the Dynamics scores I cannot conclude that by completing the mini-projects the students general MATLAB use was improved. The mini-projects need to be completed in more Dynamics classes to see if a significant improvement is observed in this area. However, it can be concluded that by completing the mini-projects the students did experience an improvement in application of MATLAB.

Table 1. Rubric for Assessment of General MATLAB Use

Score	Description
1	No knowledge of the functions available in the programming environment for solving engineering problems. Serious errors in syntax and/or inputs to functions. No ability to validate computational results.
2	Demonstrates knowledge of a subset of the features and functions available within the analytical software package. Inappropriate selection of functions available in the programming environment and/or serious errors using functions. Incomplete validation of results.
3	Demonstrates familiarity with most of the features and functions available within the analytical software package. Able to choose the appropriate functions or sequence of functions for solving a given engineering problem with minor errors in the syntax of functions or input to these functions leading to errors in results. Students have the ability to detect errors in their results
4	Demonstrates familiarity with most of the features and functions available within the analytical software package. Able to choose the appropriate functions or sequence of functions for solving a given engineering problem with minor errors in the formatting of results. At least partial validation of results is demonstrated
5	Demonstrates familiarity with the programming features and functions available within the analytical software package. Able to choose the appropriate functions or sequence of functions for solving a given engineering problem. Results are validated.

Table 2. Rubric for Assessment of Applying MATLAB to Solve an Engineer Problem

Score	**Description**
1	No ability to reduce the engineering solution process to an executable program. No ability to determine if programming problems are the result of syntax errors or logic errors. If results are obtained, there is no attempt at validating these results.
2	Significant logic/syntax errors encountered implementing algorithms for solving engineering problems leading to errors in the results. Student unable to debug program and demonstrates no attempt at validation and no realization that results are incorrect.
3	Significant logic/syntax errors encountered implementing algorithms for solving engineering problems leading to errors in the results. Student is unable to debug programs completely, but recognizes that results are incorrect
4	Able to transform engineering solutions into the structures of the programming environment. Minor logic errors and/or syntax errors. Able to debug programs and demonstrates ability to partially validate programs.
5	Ability to transform engineering solutions into an algorithmic form and then implement this form using the structures of the programming environment , such as loops, if-then-else statements, functions and subroutines. Demonstration of debugging skills and the ability to validate programs.

Outcome and Discussion

In Mini-Project 1 the students found an interesting application of particle kinematics that was not the typical textbook projectile style problems. In addition, it provided them an example of when relative motion between two particles is useful. One issue that I ran into while conducting this project is that the students believed the project was too much work for the amount of time they were given, which was two weeks. After giving the project and reflecting on the results, I do not think that the project was too much work, I believe the students were overwhelmed since it was vastly different then the textbook particle kinematic problems they had been working on.

In Mini-Project 2 the students found it interesting how dynamics principles can be used to design parts. In-class they have been learning about how to use kinematics to analyze the motion of objects but have not had the opportunity to look at it from the perspective of designing the motion of the object. While conducting this project I told the students that it is okay if their design is not manufacturable. For some students they accepted that and made a Geneva mechanism with a wheel diameter that is approximately the size of a football field. However, other teams realized that something that size is not realistic, so they made alterations to make it a little more reasonable in design.

In Mini-Project 3 the students found it interesting how they would need to develop two sets of equations to model the system. One set that modeled when the feet were above the trampoline and a second set when the feet were in contact with the trampoline. They found this interesting because they are used to finding a single solution to a problem or at least a single set of equations that model the entire motion. Overall, I found this project to have the least number of issues compared to the first two projects since it was very much like a textbook problem, but with the addition of looking at the mechanism dynamics over time.

Unfortunately, not all outcomes were positive. One of the goals of developing these mini-projects was to provide students with more programing experiences. However, since the mini-projects were conducted in groups, I noticed that one student in each group would gain a greater depth of knowledge in MATLAB and the other one-two students would have limited additional exposure to MATLAB. In the Future Work section below, I provide a proposed method for addressing this issue without adding too much additional work for the students.

Future Work

One of the issues mentioned above is having a single student in each group complete the programming alone. To combat this issue, I suggest that additional computer assignments be assigned throughout the semester as homework problems. These homework problems would be simpler then the three mini-projects mentioned above and be capable of being completed in the same timeline as a typical homework assignment. These assignments would take place of some existing homework assignments rather than be added onto.

A second area for future work is expanding the scope of one or more of the mini-projects to include building and experimental testing. For example, if mini-project two was expanded upon, the students could be tasked with building the Geneva mechanism using plywood cutouts. Then a motor could be provided with the necessary hardware to connect the motor to the mechanism. It should be mentioned that if this project was used in this application the graduation wheel would need to be changed to a smaller time limit so that it can be testing during a class period.

A third area for future work is to involve formal data collection and analysis into the projects. Take for example Mini-Project 1, instead of using given accelerations, the students could be tasked with collecting acceleration data from a small car like a retired Baja SAE (Society of Automotive Engineers) car or a remote controlled car on a prescribed course. Then, the students could be tasked with modeling that vehicle as a particle around the track to compare an analytical particle kinematic model to the real-world physical model.

Conclusion

The goal of this work was the development of a set of mini-projects that illustrate the potential of implementing programming projects in the course curriculum for a Dynamics course. In this work three mini-projects were developed that cover three of the main topics taught in the course. By conducting these projects, I found that several of the students benefited and saw an increase in their MATLAB programming skills. Throughout the semester I found that the first mini-project had the most programming questions while the third mini-project had fewer MATLAB questions because the students became more proficient and confident in using MATLAB.

References

1) Tiwari, A., Lai, P., So, M., and Yuen, K. 2006. A comparison of the effects of problem-based learning and lecturing on the development of students' critical thinking. Med. Educ. 40, 6, 547–554.
2) Walker, A. and Leary, H. 2009. A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. Interdiscipl. J. Prob.-Based Learn. 3, 1,12–43.

3) Strobel, J. and Van Barneveld, A. 2009. When is PBL more effective? A meta-synthesis of metaanalyses comparing PBL to conventional classrooms. Interdiscipl. J. Prob.-Based Learn. 3, 1, 44–58.
4) Zhao, X., Chowdhurt, S., Chowdhury, T., 2020. Integrating Evidence-Based Learning in Engineering and Computer Science Gateway Courses. ASEE Virtual Conference
5) Carrero, E., Gomar, C., Penzo, W., and Rull, M. 2007. Comparison between lecture-based approach and case/problem-based learning discussion for teaching pre-anaesthetic assessment. Euro. J.Anesthesiol. 24, 12, 1008–1015.
6) Kirschner, P. A., Sweller, J., And Clark, R. E. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educ. Psychol. 41, 2, 75–86.
7) Vector Mechanics for Engineers: Statics and Dynamics, Ferdinand P. Beer, E. Russell Johnston, et al., Twelfth Edition, McGraw Hill, 2018.