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Mentoring and Motivating Project Based Learning in Dynamics

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ABSTRACT

Students in the Department of Engineering at James Madison University choose the program for opportunities to build close relationships and experience high impact teaching. The shift to online learning due to COVID-19 resulted in a potential loss of these opportunities and a decrease in student motivation. In my Statics and Dynamics course I wondered: *How might I replicate the mentored learning experience while maintaining student motivation through the uncertainty of COVID-19?* I crafted a half-semester project where students proposed to analyze a real-world problem requiring techniques from Dynamics. The student response was overwhelmingly positive and suggested they were intrinsically motivated.

Key words: Motivation, Self-Determination Theory, Project Based Learning

INTRODUCTION

March 11, 2020: *Classes shift online for at least one week.* March 16, 2020: *Classes shift online for remainder of the semester.* March 19, 2020: *First confirmed COVID-19 case within the James Madison University (JMU) community*—a community that prides itself on community. Nestled in the Shenandoah Valley, Virginia, JMU is passionately called home to just over 20,000 undergraduates spanning 130 degree programs [1], one of which is a single degree Bachelor of Engineering—where I teach predominately first and second-year students. The program has approximately 400 majors [2], and while approximately 92% of JMU students take at least one online course during their time at JMU, prior to COVID19, there were no online-only Engineering courses offered. Being a JMU graduate myself, I am uniquely positioned to understand that students choose to come to JMU for an in-person experience characterized by peer collaborations, high impact teaching, mentored relationships (personal or professional) with faculty, and a well-rounded liberal arts education.

Using my personal understanding of the cultural underpinnings of the JMU community, I approached the transition to online as the following design challenge: *How might I replicate the deeply mentored learning experience, while maintaining student motivation through the uncertain societal challenges associated with COVID-19?* Each of the following sections follow the design mindset [3] applied to redevelop the Statics and Dynamics course I was teaching when the shift to online learning occurred. Ultimately my objectives in making this pivot were to achieve the learning outcomes of my course and to provide an opportunity for students to find a sense of certainty with respect to the course when the world felt so uncertain.

METHODS

Benchmarking

Prior to COVID19, I used a Direct Instruction (DI) pedagogical approach where I framed the content, modeled how to solve the problem, then gave a variety of assessments to evaluate mastery of the problem-solving process [4]. One of the fundamentals of DI involves the feedback between student-teacher, particularly the behaviors of students when content is presented [4]. I observed that my students were very engaged in class through participating in tasks and answering questions, which matches observations of DI's potential to increase intrinsic motivation [5]. I anticipated that the quick shift to a virtual environment would no longer allow me to utilize DI successfully, and as a result of the shift, students would exhibit a decrease in motivation towards amotivation (a disconnection between the assignments for the class and the personal "why") [6]. Inspired by the work of Stolk and colleagues [7], I opted to pivot my course from the traditional lecture with exams, to a half-semester long project where I would individually mentor the students (n=30) through an analysis of their choosing (see Appendix 1). Through my mentoring, I would guide each students' analysis to align with the course learning objectives.

Conceptualization

At the time of the transition to online, the Statics and Dynamics course was 50% complete with all content in Statics covered, but no content in Dynamics. To provide the students with agency, I used Self-Determination Theory [8] to build a framework for inquiry and investigation that would allow students to explore questions from the real-world related to dynamics. My goal was for the students to be driven strongly by intrinsic motivation as I worried that with the uncertainty of COVID19, students might struggle with engaging. I identified the following learning objectives (LO) for the remainder of the semester: (LO1) Identify a real world system and recognize the concepts of dynamics demonstrated by that system, (LO2) draw a system representation through free body diagrams, (LO3) evaluate the system using a mathematical model, and (LO4) examine how variance in parameters affects the conclusions. As a result of the redesign my learning objectives for the course became more specific than they had been originally, and I had to remove some content (see Appendix 2).

Prototyping

In order to help students identify real-world questions (LO1) that could be analyzed in the context of the course, the students proposed four textbook problems and four real-world problems that they found personally interesting (intrinsic motivation [8]). Then I setup WebEx meetings with small groups of students to talk through their identified problems. I sent each student an email afterwards providing additional guiding questions and thoughts to narrow, broaden, or shift scope for their analysis. These personal emails served to vet and ensure that each project would use a minimum of two problem solving techniques from the class (one had to be from dynamics content).

At this point, students were able to articulate a single problem and analysis, but they needed to represent the system using free body diagrams (LO2) to validate the modeling approach. Students used the representation to write equations and make appropriate assumptions to arrive at an answer (LO3). The students shared their initial results on a discussion board and provided quality control feedback to two peers (LO1 and LO3). The final step required a software tool, such as Excel or MATLAB, to perform a parameter analysis (LO4).

PRELIMINARY RESULTS

I met with students during office hours and at project specific sessions. The students asked questions and made comments that map to intrinsic motivation on the Situational Motivation Scale (SIMS) [8], but without IRB approval, I did not document these responses. On my course evaluations students articulated that they enjoyed pursuing their own curiosities and felt they learned the content better because of the connections to the real world. Overwhelmingly, they stated that I had motivated them to do their best work (4.8/5). This result was higher than prior course iterations (4.5/5).

With respect to the projects, a majority used free body diagrams to analyze forces at static and/or dynamic equilibrium. Almost half of the projects used straight line motion equation derivations for constant or non-constant acceleration, about a third of projects asked questions that used concepts of work and energy, and a third used curvilinear motion. 17 of the 29 turned in final projects used the minimum of two different types of analysis questions, while 11 of the 29 asked between one and four additional questions. 14 of the 29 projects appeared to choose analysis questions based on something they had personally experienced or wanted to experience so they could understand it better (like a roller coaster). 9 of the 29 projects specifically justified their choice of problems based on a curiosity mindset and to help them better understand class concepts. Two students explicitly stated that they were choosing problems they found interesting and personally relevant so they would be motivated to complete the final project. The majority of the projects were questions that the students generated (20/29). The rest of the projects were textbook problems that were modified or expanded upon (5/29) or textbook problems with minimal changes (4/29). Some of the most fun projects for me were the ones with questions which required concepts beyond the scope of the class.

NEXT STEPS

In Spring 2021, I plan to run an experiment to determine the motivation of students in my section versus other sections (control group). I hypothesize that creating a mentored, multi-week project will result in higher intrinsic motivation in the PBL vs control sections. To capture this, I will deploy weekly questionnaires based on the SIMS to capture the motivational response types of students throughout the semester and project [7, 9]. I am also interested in assessing student mastery of course content. I hypothesize that this type of project will result in a higher level of complex comprehension than the control because it is a PBL pedagogy [10–11]. I anticipate this assessment taking the form of a test with closed-form questions from the FE and open-form questions given to both sections. I hypothesize that the PBL group will perform just as well as the control on the FE type questions, and better than the control group on the open-form questions. The only differences I anticipate between groups are the breadth of content covered in the control group versus the depth in the PBL group (which will be highly variable depending on the projects individuals choose). Lastly, although this approach worked very well during the time of COVID19, it is entirely possible that it will not work well during a typical semester.

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AUTHOR

Callie Miller is an Assistant Professor in the Department of Engineering at James Madison University (JMU). Dr. Miller primarily teaches engineering design courses in the first two years of the curriculum and a statics and dynamics course. Dr. Miller earned a BS in Mathematics from JMU in 2008, a MA in Mathematics from the University of Pittsburgh (Pitt) in 2009, and a PhD in Bioengineering from Pitt in 2014. Dr. Miller describes herself as a "mathematically-inclined" bioengineer with research interests in developing computational simulations and data analysis tools that aid biologists in drawing experimental conclusions from microscope time-lapses. Dr. Miller sees the power of mathematics in understanding the world and enjoys connecting mathematics and physics to engineering in an accessible way for the JMU undergraduates to minimize silo-ing of topics.

Appendix 1

Dynamics – Course Project

The goal of this project is for you to demonstrate an ability to recognize the concepts of dynamics in the physical world through abstraction, representation, and modeling. You will work individually to apply statics and dynamics principles and tools to analyze a self-identified dynamics system. Throughout this project, knowledge and experience gained in class, assignments, and labs should be applied.

This project is divided into multiple weeks of tasks and milestones that must be completed in order to move through to the final deliverable. The tasks build on each other and must be completed in order, but grades for each task will be assigned at the designated due date time. For example, you may choose to not perform task 1 during week 1 so your grade will be 0 for task 1, but task 1 must still be completed in order to move onto task 2. Therefore, task 1 will not be re-graded, but task 2 will be graded.

At the conclusion of this project, you will:

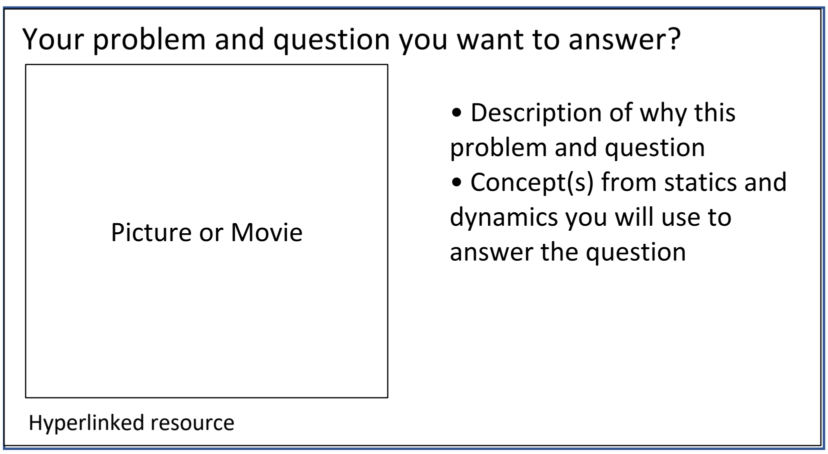
- Identify a real working system and recognize the concepts of statics and dynamics demonstrated by that system.
- Describe why you want to model this real working system.
- Identify the analysis to be performed and articulate the reason for the analysis.
- Identify the variables to be included in the analysis.
- Identify the assumptions and approximations that will be used.
- Draw a system representation (i.e., Free-Body Diagram).
- Develop a mathematical model(s).
- Evaluate system characteristics caused by variable variance using the mathematical model(s).
- Accurately and appropriately use a modeling tool (Excel, MATLAB, etc) for analysis.
- Qualitatively describe the system based on characteristics learned about the system from the mathematical model(s).

Task 1: Identify a real working system

During dynamics, we will focus on solving problems of objects in motion. Specifically, we will consider systems as objects while moving in a straight line, around a curve, use conservation of energy to determine properties of the system, look at rotating systems, and use conservation of momentum to describe simple collisions of objects. If you look through your textbook, however, there is a lot more to dynamics than just these introductory topics. Based on the system you choose, you may find you need to learn beyond the scope of this course in order to fully analyze your chosen system- that's awesome!

It's a daunting challenge to be told "identify a real working system" that you know you will ultimately need to analyze (and be graded on that analysis!), so you will need to first explore a bunch of various systems that you might choose to focus on. First, go through the textbook and find at least 4 problems that peak your interest as a system to analyze. Second, either from the world around you or through the internet, find at least 4 additional problems that peak your interest as a system to analyze. This could be clips from a movie, tv show, YouTube, Reddit, Instagram, Facebook, a song, etc. You are invited to find even more problems, through the textbook or other resources, but the expectation is a minimum of 8.

Deliverable: Create a powerpoint slide for each problem you identified (i.e. a minimum of 8 slides). Your slides should be set up to include a descriptive picture (or movie), drawn or actual, that clearly shows the system you're proposing to study, a hyperlink to website resources (or in the case of the textbook, the problem number, page number, etc), the question(s) you aspire to solve with your analysis, a description of the concept(s) from statics and dynamics you believe will be needed in your analysis, and a description of why you want to model this system.



You will upload a pdf of your powerpoint slides.
Grading: You will be assessed not only on quantity of problems identified, but quality. Problems identified should obviously align with the topics in the course, the powerpoint template should be adhered to, appropriate citations included, clear images/videos, robust descriptions of the material

from class needed to solve your question, and a complete description as to why you want to model this system. I am looking for clear descriptions and questions, creativity, and professionalism.

Task 2: Narrowing Scope

Before we jump into analyzing, we need to further develop our understanding of the problem at hand through abstracting the real-world system into a diagram. Additional questions frequently arise as we consider how to go about modeling a system. What are you forgetting to consider? What simplifications can be made?

Deliverable: Choose your favorite two ideas from Task 1 and add an additional powerpoint slide for each idea to share a conceptual diagram or picture/graphical model of the system. You will meet with a small group of peers and Dr. Miller using WebEx to share out, receive feedback and further iterate through project possibilities. You will share your 2 slides from your favorite ideas with the group and everyone will tell you 2 likes and 1 wish. Additionally, you must prepare a minimum of 2 questions to ask the group that will help you iterate through your analysis.

Dr. Miller will notify you by Wednesday, April 1 when your group meeting time via WebEx will be held, or if you will be making a pre-recorded video to share in a group discussion board for receiving and giving feedback. These meetings will occur between Wednesday April 1 and Friday April 3. You must fill out this quiz of availability and upload your slides as a pdf by Tuesday, March 31 at 11:59 pm.

Grading: You will be assessed on your feedback and participation, your prepared questions to the group that are aiming to help you iterate through your analysis, and your professionalism in communicating your ideas.

Task 3: Final selection and preliminary analysis

Before we analyze any system, we must know what we want to learn from the analysis. What is your goal in doing this analysis? Is it to understand how something works (such as ramped turns on a race track)? Or is it to improve the system (such as changing material properties of an object such that the coefficient of restitution is altered reducing impact forces)? You need to select one of your ideas from Task 2 for moving forward. Your analysis must include two techniques of solving problems from class. For example, a static analysis to determine a normal force which is then used to determine the force of friction for your system in motion. Or an analysis of a system moving in a straight line versus in a curve. Or an analysis of the impact of an object using conservation of energy to determine velocities before impact. One technique must be from dynamics: straight line motion, work and energy, curvilinear motion, rotational motion, or impulse and momentum.

Deliverable:

- Refine your powerpoint slides so that Slide 1 includes the problem you've identified, the question(s) you have, and why you want to model this system.
- Slide 2 is your diagram and graphical model of the system.
- Slide 3 is your proposed steps for analyzing. Identify the analysis to be performed and articulate the reason for this analysis. At the bottom of this slide, reiterate how the answer to this analysis relates to your initial question. In addition, include a brief hypothesis statement. For example, if your question was at what point during a circular loop did a rider on a roller

coaster experience the most g-forces, you might hypothesize that this would be the same throughout the loop because it is a circle.

- Slide 4 will include all the pieces of information needed to conduct your analysis. Identify the variables you need, and the assumptions and approximations that you will use with references cited as hyperlinks on the slide in appropriate places.
- If you have multiple questions or steps needed to answer your question you will need additional slides. Structure them in the Slide 3 and Slide 4 formats so it is clear to the observer/reader how you are using these steps to proceed through the process and answer your question(s).

Grading: You will be assessed on your professionalism in communicating your ideas, your ability to break down your question(s) into a conceivable analysis, your ability to determine all variables and assumptions needed, how you hypothesize the results of an analysis and how that informs your questions and process. I am looking for analyses that include at least two topics from the class in order to answer your posed question(s), a clear process from question to analysis, appropriate citations, clear images/videos, creativity, and professionalism.

<u>Task 4: Quality Control feedback</u>
The quality control process is common in engineering practice as work must be reviewed before delivering it to your client(s). We will utilize this process to check the analysis and proposed model for the problem.

Deliverable: Add a slide 5 to your slide deck of your actual analysis. Equations must be added with a description of why they were included and how your analysis proceeds. Put in numbers and actually solve for the answer. Since you are not actually giving a presentation with a projector, you may use smaller size fonts and different organization in the ppt slide itself to communicate your process more clearly. Think of this slide deck as being a mini-report. Slide 6 is a reflection on your solution: Does it make sense? Does it answer your initial question? Why or why not? Does it follow your initial hypothesis? Why or why not? What additional questions do you have?
If you have multiple "slides 3 and 4" for your analysis, you will need to include the appropriate slides 5 and 6 for them.

You will upload your slide deck to this assignment as a pdf.
Then, you will upload your slide deck to the Task 4 Discussion Board, and provide a quality control feedback for a minimum of 2 peers . In the interest of making sure that everyone receives feedback and a quality control check, you must search for peers who have not received any feedback before providing feedback to someone who has already gotten a response. Your feedback and quality control review should either be in the form of a discussion post response, or an uploaded document (pdf) so that equations and notes can be seen. The discussion board feedback must be completed by Monday, April 20 at 11:59 pm.
Grading: You will be assessed on your professionalism, thoroughness of your analysis process, correctness of your equations and numbers, and your reflection on the result. Additionally, you will be assessed on your feedback and participation to your peers during the quality control process via the discussion board (this grade will be in the discussion board assignment).

Task 5: Evaluating variability

As you've seen in homework problems, engineering practice problems, and lab assignments, there is variability present in real-world system which can impact your solutions. Just as you perform testing and refinement in engineering design to perfect your design and understand it better, understanding the variability present in your analysis is critically important to refining and justifying your mathematical models. You will critically examine the variability that might be present in the system, either due to the limiting assumptions you made, or further research you need to conduct into system variability. If you haven't used a software tool (i.e. Excel or MATLAB) for your analysis, it might be very helpful to develop that tool now as you introduce variability into the system.

Deliverable: Add a slide 7 to your docu-presentation slides that describes the system variability present in your project, the impact the variability has on the solution, and why it is important to consider it. There might be a huge array of variability you could consider for your project, however, choose sources of variability that make the most sense for critically examining your question(s). For example, if you wanted to know the maximum speed you could take in a circular exit ramp from the interstate, you might choose to focus on variability in the banked angle of the ramp, the radius of the circle, and the coefficient of friction between the tires and the road. If you were, instead looking at the maximum speed for a specific type of car (weight, size, acceleration, etc), then you might vary the car parameters to look at a different type of vehicle instead of variables pertaining to the exit ramp. You may choose, however, to look at all variables, but the expectation is to have enough material to fill one slide in your docu-presentation in a formal format with small font size.
You will also need to upload your code, either Excel or MATLAB, that you created for examining your variability in your system. Your "code" should be well commented/documented so someone who isn't you can follow what you did and why you chose to look at the numbers in the way you did. Variables should be self-explanatory, or have an associated comment to tell the user what they mean. If there's a specific range that's realistic for a certain variable (i.e. for a coefficient of friction, that number can't be negative, and probably shouldn't be zero. It also can't be greater than 1), that should also be commented.

You will upload your slide deck, docu-presentation, as a pdf to this assignment. Additionally, you will upload your code (either MATLAB -m files or Excel spreadsheets) for examining variability. Grading: You will be assessed on your professionalism, your justification for examining variability in your problem, and your explanation for why examining variability is important for your problem. Your code files will be assessed based on professionalism, readability or ease of use, correctness from the equation analysis to building in variability, and helpfulness in addressing the questions of variability present in the system.

Task 6: Report Out

One critical role of engineers is to communicate designs, problems, and solutions. Your final project will be a written and a docu-presentation of your system. Your communication will include the system, your diagram representation of the system, your mathematical model, assumptions made, variance evaluation of your system variables, analysis of the system using modeling tools (such as MATLAB or Excel), and a qualitative description of the system based on your analysis.

Deliverables:

1. (20 points) A written memo of your system to be analyzed, analysis, and qualitative description (*this file should be uploaded to the Task 6 assignment as a pdf)*
2. (10 points) Your modeling tool file used for analysis (Excel or MATLAB) (*this file should be uploaded to the Task 6 assignment as either an .m file or .xls file. If you have used a different platform for analysis, you must also include a "readme.txt" file to describe how a user can open your file, i.e. which program needs to be downloaded, if it can only be opened on a mac or pc, etc)*
3. (20 points) Your docu-presentation slides (*this file should be your final product of slides as a pdf or pptx. You do not need to designate which slides are "Task 1, 2, 3, etc" just consider all of the tasks to "blur" together to support and create your final project)*
4. Upload your docu-presentation slides to the appropriate discussion board on Canvas: Task 7 feedback

Grading: Your memo will be assessed separate from your docu-presentation slides, and your "software" file. Your "software" file will be assessed based on usability (is it well commented and user-friendly to operate) and correctness. Your memo will be assessed on professionalism, appropriate documentation and references for assumptions and analysis steps, descriptive and appropriate figures, correctness of your analysis, and appendices of supporting materials. Your docu-presentation slides will be assessed on professionalism, if they are visually appealing, if the process of presentation and layout makes sense for your problem, and how you are able to communicate your understanding of the problem you've chosen to study.

<u>Task 7: Feedback</u>

Provide a graded feedback of 4 of your peer's projects based on the following rubric (see this document LASTNAME_comments_PEERNAME.docx). You will download this document, fill in appropriate information, and rename the file "YOURLASTNAME_comments_PEERLASTNAME.pdf" You will be graded on the quality of your feedback and constructive critique you provide to your peers. Your feedback should be given in response to your peer's discussion post via a pdf file upload in a threaded response.

I expect constructive and valuable feedback to your peers. Helpful and high quality feedback looks like probing and challenging questions, thoughtful comments with reasons and justifications for your rubric choices, catching serious mathematical errors, etc). Unhelpful feedback looks like making a suggestion for a change without explanation or justification, positive comments with no reasoning, or missing mathematical mistakes.

Peer's Name:
Peer's Project Title:

Your Name:

Category	**Grade**	**Explanation**
Curiosity		
Representation		
Assumptions		
Calculation		
Application/Analysis		
Sources and Evidence		
Professionalism of Writing		

Category	Capstone	Milestones		Benchmark	Failed Benchmark
	A	B	C	D	F
Curiosity	Explores a topic in depth, yielding a rich awareness and/or little-known information indicating intense interest in the subject	Explores a topic in depth, yielding insight and/or information indicating interest in the subject	Explores a topic with some evidence of depth, providing occasional insight and/or information indicating mild interest in the subject	Explores a topic at a surface level, providing little insight and/or information beyond the very basic facts indicating low interest in the subject	
Representation *Ability to convert relevant information into various mathematical forms (e.g., equations, graphs, diagrams, tables, words)*	Skillfully converts relevant information into an insightful mathematical portrayal in a way that contributes to a further or deeper understanding	Competently converts relevant information into an appropriate and desired mathematical portrayal	Completes conversion of information but resulting mathematical portrayal is only partially appropriate or accurate	Completes conversion of information but resulting mathematical portrayal is inappropriate or inaccurate.	
Assumptions *Ability to make and evaluate important assumptions in estimation, modeling, and data analysis*	Explicitly describes assumptions and provides compelling rationale for why each assumption is appropriate. Shows awareness that confidence in final conclusions is limited by the accuracy of the assumptions.	Explicitly describes assumptions and provides compelling rationale for why assumptions are appropriate.	Explicitly describes assumptions	Attempts to describe assumptions	
Calculation	Calculations attempted are essentially all successful and sufficiently comprehensive to solve the problem. Calculations are also presented elegantly (clearly, concisely, etc)	Calculations attempted are essentially all successful and sufficiently comprehensive to solve the problem	Calculations attempted are either unsuccessful or represent only a portion of the calculations required to comprehensively solve the problem	Calculations are attempted but are both unsuccessful and are not comprehensive	

Application/Analysis *Ability to make judgments and draw appropriate conclusions based on the quantitative analysis of data, while recognizing the limits of this analysis*	Uses the quantitative analysis of data as the basis for deep and thoughtful judgments, drawing insightful, carefully qualified conclusions from this work.	Uses the quantitative analysis of data as the basis for competent judgements, drawing reasonable and appropriately qualified conclusions from this work.	Uses the quantitative analysis of data as the basis for workmanlike (without inspiration or nuance, ordinary) judgments, drawing plausible conclusions from this work.	Uses the quantitative analysis of data as the basis for tentative, basic judgments, although is hesitant or uncertain about drawing conclusions from this work.	
Sources and Evidence	Demonstrates skillful use of high-quality, credible, relevant sources to develop ideas that are appropriate for the discipline and genre of the writing	Demonstrates consistent use of credible, relevant sources to support ideas that are situated within the discipline and genre of the writing	Demonstrates an attempt to use credible and/or relevant sources to support ideas that are appropriate for the discipline and genre of the writing	Demonstrates an attempt to use sources to support ideas in the writing	
Professionalism of writing	Uses graceful language that skillfully communicates meaning to readers with clarity and fluency and is virtually error-free.	Uses straightforward language that generally conveys meaning to readers. The language in the portfolio has few errors.	Uses language that generally conveys meaning to readers with clarity, although writing may include some errors.	Uses language that sometimes impedes meaning because of errors in usage.	

This rubric was created using the Association of American Colleges and Universities (AAC&U) Foundations and Skills for Lifelong Learning VALUE Rubric, Quantitative Literacy VALUE Rubric, and Written Communication VALUE Rubric. Retrieved from https://www.aacu.org/value-rubrics

Appendix 2

Course Outcomes for the Statics & Dynamics course:

1) Construct free-body diagrams and write corresponding equilibrium equations to represent a loading scenario
2) Analyze particles, systems of particles, and rigid bodies by applying kinematics, energy, and momentum methods
3) Conduct an experiment and analyze resulting data
4) Use computer tools to solve statics and dynamics problems
5) Communicate results of experiments via written and oral presentations

At the time of the switch to online learning, only outcome 2 and part of outcome 4 had not been met.

Content topics for the dynamics portion of the class (content not covered due to COVID19 switch to online learning is crossed out):

1. Straight line motion: constant and non-constant acceleration
2. Work and Energy: non-conservative forces, ~~power~~
3. Curvilinear Motion: normal and tangential acceleration
4. Rotational Motion: inertia, ~~work and energy, power~~
5. Impulse and Momentum: simple impacts, conservation of linear momentum, coefficient of restitution~~, oblique impacts~~