Beyond the Final Answer: Using Multi-Path Problems for Deeper Insight in Student Learning and Formative Assessment

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Dr. Anurag Purwar is an Associate Professor of Mechanical Engineering at Stony Brook University. His research interests are in bringing together rigid body kinematics and machine learning for design of mechanisms and robots. He has published 109 peer-reviewed conference and journal papers and his research has been funded by National Science Foundation (NSF), NY-state SPIR, NY-state Center for Biotechnology, Sensor-CAT, SUNY Research Foundation, industry, Stony Brook University, and SUNY Office of Provost.

He received A.T. Yang award for the best paper in Theoretical Kinematics at the 2017 ASME Mechanisms and Robotics Conference and the MSC Software Simulation award for the best paper at the 2009 ASME International Design Engineering Technical Conferences (IDETC) . He is the recipient of the Presidential Award for Excellence in Teaching by Stony Brook University and the winner of the 2018 FACT2 award for Excellence in Instruction given to one professor from the entire SUNY system. He also received the 2021 Distinguished Teaching Award from the American Society of Engineering Education (ASEE) Mid-Atlantic Division.

He has been twice elected as a member of the ASME Mechanisms and Robotics committee and served as the Program Chair for the 2014 ASME Mechanisms and Robotics Conference, as the Conference Chair for

the 2015 ASME Mechanisms and Robotics Conference and has served as symposium and session chairs for many ASME International Design Engineering Technical Conferences. He was the general Conference Co-Chair for the 2016 ASME International Design Engineering Technical Conferences (IDETC/CIE).

He won a SUNY Research Foundation Technology Accelerator Fund (TAF) award, which enabled him to develop a multifunctional Sit-to-Stand-Walker assistive device (http://www.mobilityassist.net) for people afflicted with neuromuscular degenerative diseases or disability. The technology and the patent behind the device has been licensed to Biodex Medical Systems for bringing the device to institutional market. The device won the SAE Top 100 Create the Future Award in 2016. Dr. Purwar gave a TEDx talk on Machine Design Innovation through Technology and Education which focused on enabling democratization of design capabilities, much needed for invention and innovation of machines by uniting the teaching of scientific and engineering principles with the new tools of technology. Five of his patented inventions have been successfully licensed to the companies world-wide.

Dr. Purwar is the Secretary and Chair-Elect of the the ASME Mechanisms and Robotics Committee and a senior member of the National Academy of Inventors (NAI). He is currently an Associate Editor of the ASME Journal of Mechanical Design.

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Hadas Ritz is a senior lecturer in Mechanical and Aerospace Engineering, and a Faculty Teaching Fellow at the James McCormick Family Teaching Excellence Institute (MTEI) at Cornell University, where she received her PhD in Mechanical Engineering. Among other teaching awards, she received the 2021 ASEE National Outstanding Teaching Award.

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Abstract:

This project is presented as a Work-In-Progress. Use of auto-graded online homework in engineering mechanics courses such as Statics and Dynamics has several benefits for both students and faculty. For example, students are able to receive instant feedback, while faculty don't have to hand grade dozens if not hundreds of problems in a timely manner. One significant drawback to these systems is the reliance on a single correct answer that can't capture how a student went about solving the problem. As a formative assessment tool, auto-graded homework does not lend itself to providing instructors with insight on what concepts their students are grasping well, and what they may be struggling with. Additionally, since many mechanics problems have multiple correct ways to solve the problem, it would be useful to capture how the students find their answers.

A new problem type called Multi-Path Problems (MPP) has been developed by McGraw Hill for their Connect online homework platform. MPPs include a problem statement similar to typical end of section or chapter problems found in textbooks, but instead of only capturing the students final answer, the problem is scaffolded with ten or more individual questions walking the students through the various steps of solving the problem. Students are allowed to explore various paths as they work through the problem without the software forcing them to take a particular approach. For example, a student may choose to use either a graphical method or a vector math method for solving a static equilibrium problem.

This project seeks to better understand how MPPs can be used to strengthen formative assessment of student learning. Faculty at two different universities assigned the same MPP in their respectively dynamics courses. The authors developed a visual flowchart to quickly illustrate how their students approached the problem, including what steps they took. Additionally, a comparison of how students interacted with the MPPs compared to other assignments was conducted. In general, the students were actively engaging with the MPP for a much longer amount of time than their regular online homework. There wasn't any statistically significant correlation between student performance on MPPs and that of regular online homework, quizzes or exams. However, students that made significantly more attempts to complete the MPP did have lower grades on quiz and exam questions focused on the same topics, indicating that MPPs could make for an early warning system to identify concepts students may not fully understand.

Introduction:

Undergraduate level mechanics courses such as statics and dynamics are often required courses for a number of different engineering bachelor's degrees. As such, enrollments in these courses can be quite high compared to upper division, discipline-specific courses, necessitating a time efficient method for grading assignments such as homework. Development of auto-graded homework typically administered through an online software platform associated with the textbook publisher has been on-going for many years[1] and has become quite versatile, allowing for a variety of problem types including free body diagrams[2-6].

While auto-graded online homework systems have become commonplace and quite sophisticated, the current systems cannot fully replicate the learning and feedback experience of hand-written work, especially during the formative learning phase of a new concept. Typically mechanics problems have multiple steps and even multiple correct solution paths, something that is not captured by the current online systems. It can be helpful for an instructor to see how students are approaching a problem and if there are some common mistakes being made that can be addressed in class.

Recently, a leading publisher of engineering mechanics textbooks, McGraw Hill, has developed a new auto-graded online homework problem type called Multi-Path Problems (MPP) that aims to capture more than just a student's final answer to a problem. MPPs are highly scaffolded problems that initially resemble a standard end-of-chapter problem, utilizing the same type of problem statement for the student to follow. Where MPPs differ is their inclusion of a series of questions embedded into the problem. Instead of the student working through the problem on their own and entering their final answer into the homework system, the student is asked numerous multiple choice and numerical answer questions guiding the student through the entire process. Additionally, the MPPs do not force the student to solve each problem in a particular manner when multiple correct approaches exist. Throughout an MPP, certain multiple-choice questions can have multiple correct choices that would guide the student through differing branches of the problem. For example, a student may choose to analyze the forces in the members of a truss using the method of sections, or they may choose to use the method of joints. Either method would be acceptable, and the MPP would allow the student to choose which method they want to use and then proceed through the problem using that approach.

In the fall 2024 and spring 2025 semester, the authors assigned a common MPP in their respective dynamics courses to test out the new system in the hopes of better understanding how their students were approaching the problem. One section of the course was used from two different public institutions, both with relatively small enrollments of 17 and 10 respectively. One course was a fully online, asynchronous 3 credit dynamics course while the other was a traditional in-person lecture course. The MPP selected for this study is focused on helping students understand the relationships between work, power, and efficiency and was assigned as a standalone homework assignment shortly after introducing these topics in their classes. The initial problem statement is provided in the appendix, while a flowchart illustrating the entire sequencies of questions that the students could follow to reach their final answer will be discussed in the Methodology section below. A brief discussion of the initial results of this study is included followed by the planned future work.

Methodology:

During a beta test of one of the new MPP problems this fall 2024 and spring 2025 semesters, the authors wanted to see how the students would interact with the long form, scaffolded problem and (hopefully) better understand the applied concepts after completing the problem. One early discovery was a lack of visualization for how the students were approaching the problem. While the instructor could go into the online system and see how the students answered each step, and therefore piece together their overall approach to the problem, it ended up being a very time-consuming process that had to be conducted for each student individually. As a result, the authors decided to create a visual flowchart for the entire MPP, including the different paths the students could take, and overlay the approach taken by their students. The final flowchart is shown in Figure 1.

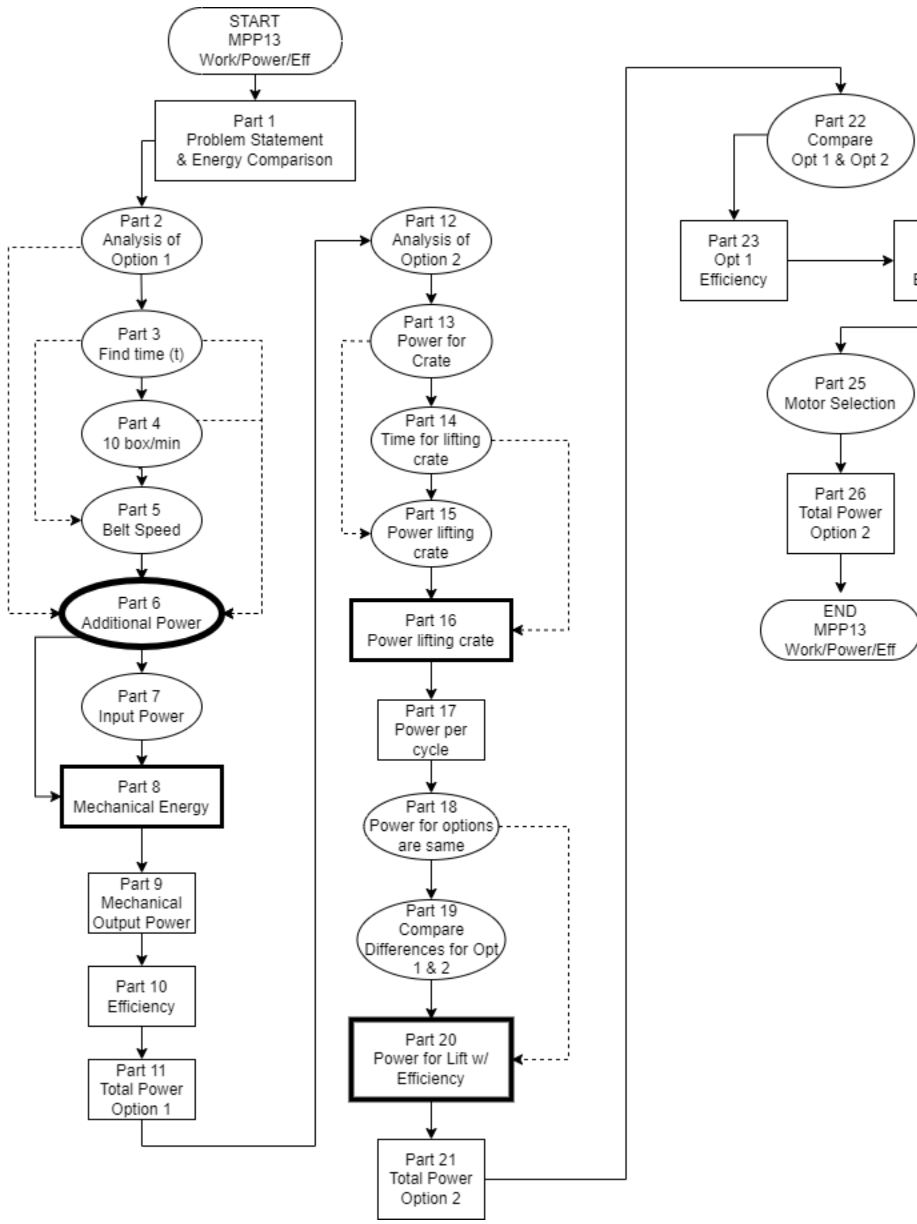

Figure 1: Flowchart for MPP13 Power, Work and Efficiency

The flowchart is designed to be a quick, graphical way to view all the steps that have been coded into the MPP. The oval "parts" represent multiple-choice questions, while the rectangular "parts" represent numerical response questions. Depending on how the student choose to approach the problem, some "parts" may be skipped, which is represented by the dashed lines. In Figure 2, the approach taken by student 01MB is shown by the highlighting of each “part” completed by the student. Green is used to indicate correct responses, although not necessarily on the first attempt. If a student was unable to correctly answer a “part”, red would be used to indicate where the student answered incorrectly and was unable to proceed. Figure 3 shows the same flowchart but with the aggregate data for the entire class, with the numbers indicating how many students answered that particular “part” with both the correct and total attempts in the following order: correct/total. The goal of the aggregate flowchart would be to see if multiple students were struggling with the same “part” of the problem, and thus the instructor could address this common issue in the course.

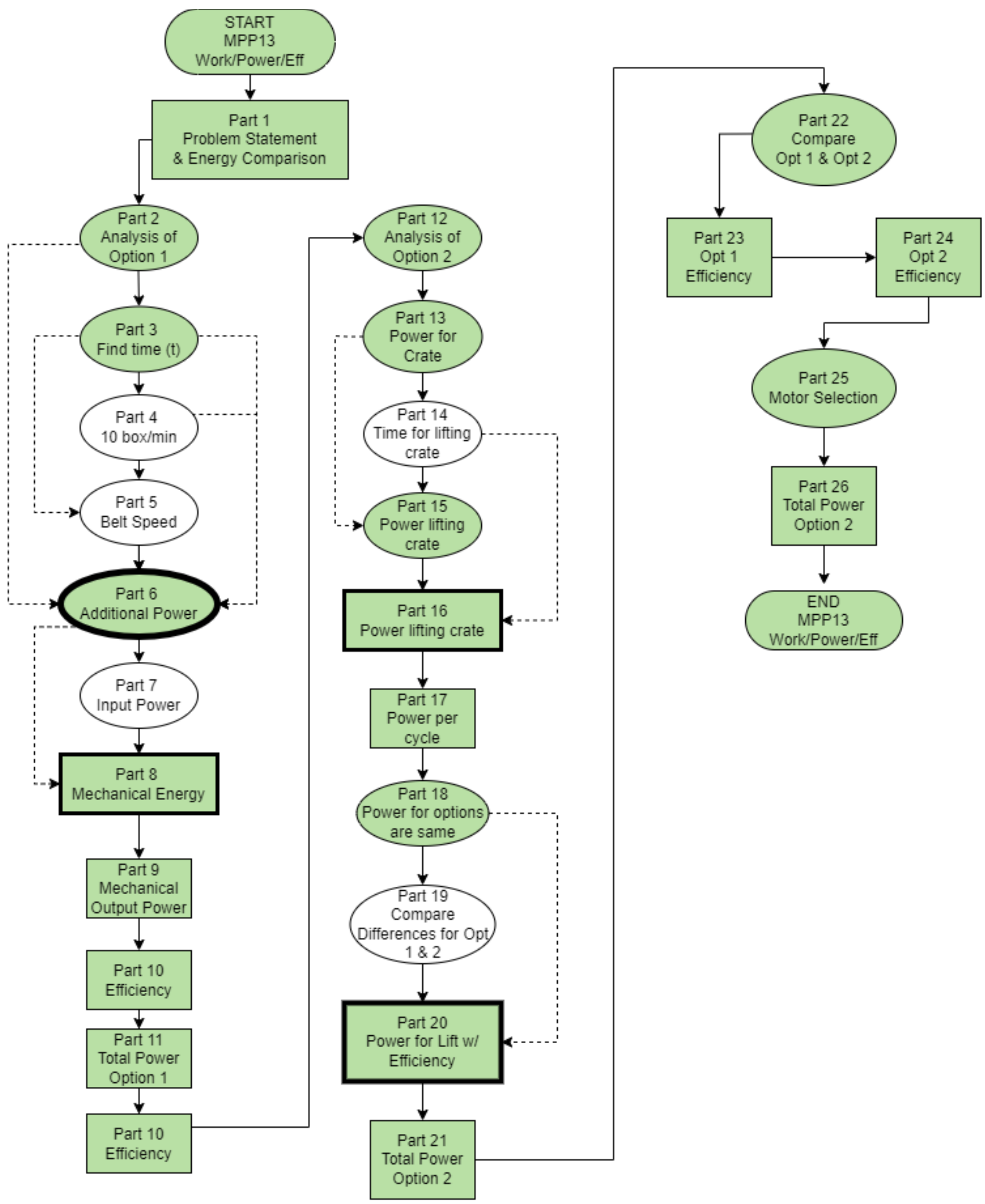

Figure 2: MPP Flowchart showing how student 01MB approached the problem

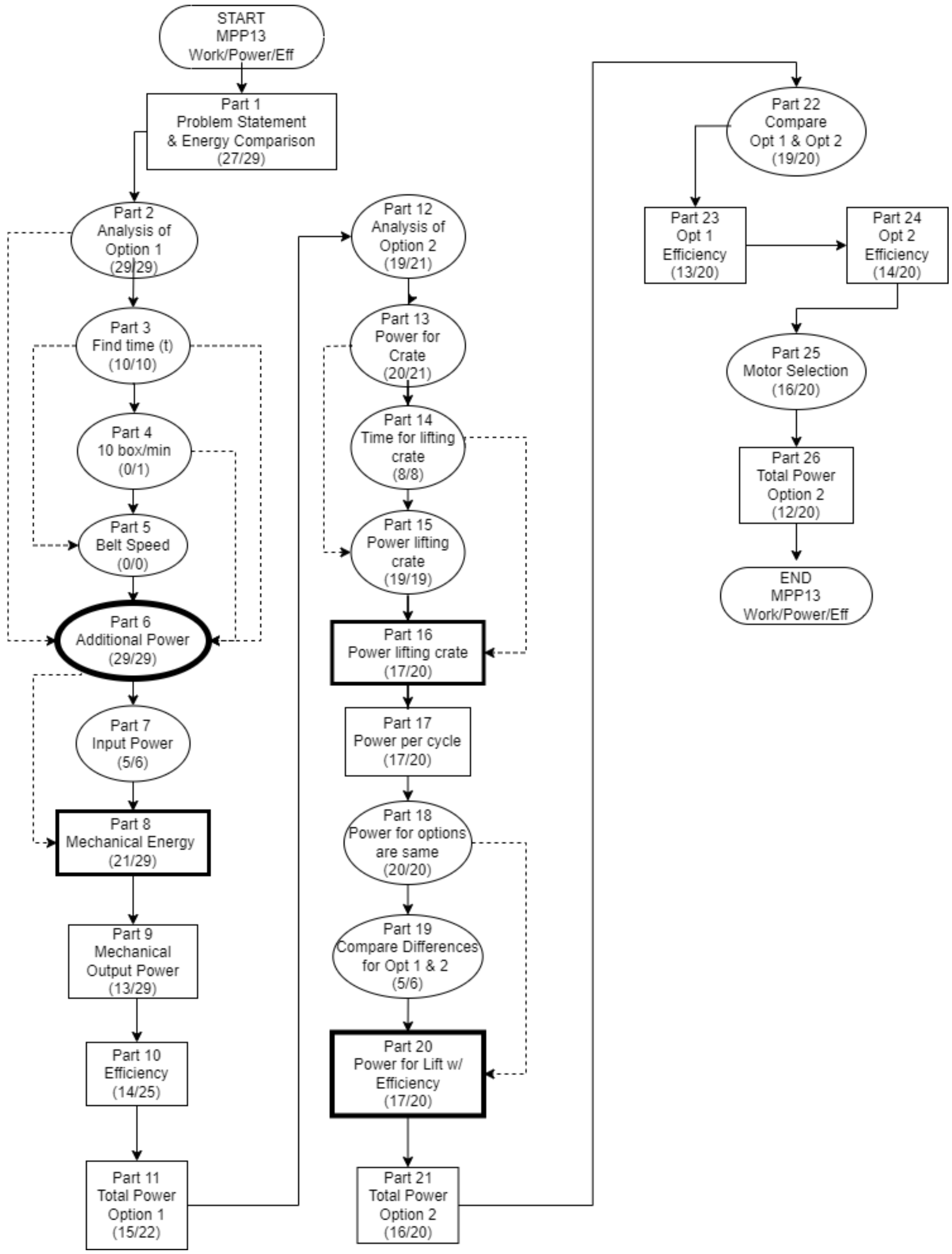

Figure 3: MPP Flowchart showing combined correct attempts and total attempts for each step

The authors also wanted to see how the students were interacting with the MPP compared to the regularly assigned end-of-chapter (EoC) homework problems and see if the MPPs provided any insight into how a student might perform on a higher stakes question in a quiz or exam. Table 1 below is the summary of the asynchronous online students' performance on the MPP, EoC HW, and Quiz and Exam questions that were related to the MPP topic. Data for only 12 students from the class were used as only 12 of the 17 students attempted the MPP and remained in the course through the entire semester.

Table 1: Summary of student data for multiple assignment types

	MPP			HW					Quiz		Exam Questions Score		
Student	Att.	Grade	Time (min)	Avg Att.	Avg Grade	Avg Time	Avg Time Que	Avg Time topic Que	Score	Time	Energy	Power	Course Grade
01MB	1	100%	47	1.05	95.0%	154.6	17.55	18.13	100	38	100	100	A
02MB	1	71%	60	2.50	100.%	70.6	7.03	9.56	30	26	100	63.16	C
	2	18%	15										
	3	18%	4										
	4	18%	5										
	5	86%	60										
	6	90%	11										
	7	95%	6										
	8	100%	6										
03GB	1	43%	4	2.30	99.6%	40.5	4.59	0.88	100	18	70.03	100	B
	2	14%	1										
04WJ	1	17%	27	2.50	98.8%	218.4	21.36	28.31	75	40	63.03	70.03	B
	2	17%	8										
	3	17%	14										
	4	35%	9										
	5	95%	34										
	6	100%	5										
05BL	1	90%	37	2.60	100.%	94.7	11.56	10.00	100	15	100	100	A
06RL	1	35%	27	1.00	81.5%	85.2	10.01	5.88	100	13	100	100	A
	2	100%	5										
07BM	1	91%	60	1.85	99.8%	56.9	5.97	5.69	100	28	100	77.03	A
	2	100%	8										
08AP	1	96%	60	1.15	73.4%	118.9	13.42	19.19	80	39	91.04	84.03	B
09LT	1	61%	60	1.25	62.4%	179.6	17.72	15.69	85	28	0	0	F
10MT	1	90%	12	2.05	100.%	23.9	3.30	4.38	100	7	100	100	A
11KT	1	17%	60	1.35	98.4%	84.0	9.08	13.31	100	11	100	100	A
	2	95%	26										
	3	100%	4										
12CU	1	45%	49	1.05	80.7%	94.8	10.28	12.00	100	24	91.04	100	B

The MPP, EoC HW, and Exams were administered through the auto-graded online homework system from the publisher, while the quiz was administered through the university's Learning Management System (LMS). The listed time for the MPP and HW was taken from the publisher's online system, which simply records how long the student has any particular assignment open in their browser. Students were allowed to complete the assignments wherever they chose. The HW data includes the average time taken to complete a HW problem for the entire course, as well as the average time spent on just the HW problems related to the MPP topics, Work, Energy, Power and Efficiency (Avg Time Topic Que). The Quiz time was taken from the LMS and is a more accurate representation of the actual time a student spent on the single problem as a recording proctor system was used for the quiz, recording the students while they completed the time-restricted single problem quiz. Students were limited to 60 minutes to complete the quiz once they started. No time was available for the exam questions as the publisher's online system could only report on the total time taken to complete the entire exam.

Questions given to students on MPP, EoC homework problems, Quiz, and exam can be rated using Bloom's Taxonomy (Bloom et al., 1956). While a formal analysis of these questions has not been conducted, we note that the MPPs primarily focus on application and analysis, as they guide students through problem-solving processes. In contrast, traditional end-of-chapter (EoC) homework problems tend to emphasize application with less structured guidance and are easier than the MPP. Quiz and exam questions vary from understanding to evaluation.

The smaller in-person course didn't utilize the same HW, quiz and exam formats and therefore did not generate the same data as the asynchronous course. However, comparative data for the MPPs is possible and shown below in Table 2. The first 12 students are from the online course and the bottom 8 students (highlighted in blue) are from the in-person course. The in-person course only allowed one attempt for the MPP's, which is why those students only have one attempt. The headers 1-26 correspond to the 26 different parts of the problem as shown on the flowchart, Figures 1-3. A "+" indicates the student correctly answers that part, while a "-" indicates the student incorrectly answered that part, but was still allowed to move forward in the problem. The columns highlighted in yellow are numerical answer questions. The majority of missed questions, 59%, were numerical answer questions. Finally, the beige highlighted cells were parts that were not attempted by that student.

Table 2: Summary of student interactions with the MPP

Student	Att	Grade	Time (min)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
01MB	1	100%	47	+	+	+			+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+
02MB	1	71%	60	+	+				+		-	-	-	-	+	+		+	+	+	+	+	+	+	+	+	-	+	-
	2	18%	15	+	+				+		+	-	-	-															
	3	18%	4	+	+				+		+	-	-																
	4	18%	5	+	+				+		+	-	-																
	5	86%	60	+	+				+		+	-	-	-	+	+		+	+	+	+	+	+	+	+	+	+	+	+
	6	90%	11	+	+				+		+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	7	95%	6	+	+				+		+	-	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
	8	100%	6	+	+				+		+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
03GB	1	43%	4	+	+	+	-		+	-	-	-	-	-	+	+		+	-	-	+		-	-	+	-	-	+	-
	2	14%	1	+	+				+		-	-	-																
04WJ	1	17%	27	+	+	+			+		-	-																	
	2	17%	8	+	+	+			+		-	-																	
	3	17%	14	+	+	+			+		-	-																	
	4	35%	9	+	+	+			+		+	+	+	+	-	-													
	5	95%	34	+	+	+			+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	-
	6	100%	5	+	+	+			+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+
05BL	1	90%	37	+	+				+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	-	+	-	+
06RL	1	35%	27	-	+				+		-	-	-	-	-	+		+	-	-	+		-	-	+	-	-	+	-
	2	100%	5	+	+				+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+
07BM	1	91%	60	+	+				+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	-	-
	2	100%	8	+	+				+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+
08AP	1	96%	60	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	-	+	+	-
09LT	1	61%	60	+	+				+	+	+	-	-	-	+	+	+	+	+	+	+	-	+	-	+	-	-	-	-
10MT	1	90%	12	+	+				+		+	+	+	+	+	+	+		+	+	+		+	+	+	-	-	+	+
11KT	1	17%	60	+	+	+			+		-	-																	
	2	95%	26	+	+				+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	-	+
	3	100%	4	+	+				+		+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+
12CU	1	45%	49	-	+				+	+	+	-	-	-	+	+	+	+	-	-	+		-	-	-	-	-	+	-
13CD	1	70%	54	+	+	+	+	+	+		+	+	+	+	-	+	+	+	+	+	+		-	-	+	-	-	+	+
14DH	1	55%	44	-	+	+			+		+	-	-	-	+	+		+	-	+	+		-	+	+	-	+	-	-
15DH	1	71%	16	-	+	+			+		+	+	+	-	+	+		+	+	-	+		-	-	+	-	+	+	+
16WK	1	0%	0	-																									
17LK	1	100%	23	+	+	+			+	+	+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+
18ER	1	0%	8	-																									
19ER	1	90%	38	+	+				+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	-	+	+	-
20MS	1	71%	60	+	+				+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	-	-	-	-

Results: Due to the small sample size and limited data available, any correlations between MPP performance and EoC HW, Quiz and Exam performance would be statistically insignificant and no strong conclusions can be drawn at this point; however, some potential trends can be seen and will be briefly discussed.

MPP Results: All but two of the students used between 1 and 3 attempts to solve the MPP problem, with the other two students using 8 and 6 attempts respectively. Students were allowed unlimited attempts, but had to start over on each new attempt and the highest score was used for their final grade. Eight of the twelve students were able to completely solve the problem with a score of 100%, with nearly all incorrect answers occurring on a numerical response question rather than a multiple-choice question. The average time students spent working on the MPP (59.9 min.) was significantly higher than the time spent on a EoC HW problem (23.9 min.) or Quiz problem (11.0 min.). Note: it was not possible to separate out time spent on individual exam questions. While the authors have posited that spending more time on the MPP may translate to increased knowledge, and therefore less time spent solving HW or Quiz problems, the data shows a clear positive relationship between those times as is shown in Figures 3-6 below. In general, the limited data indicates student work habits are far more indicative of how much time they will spend on any given assignment.

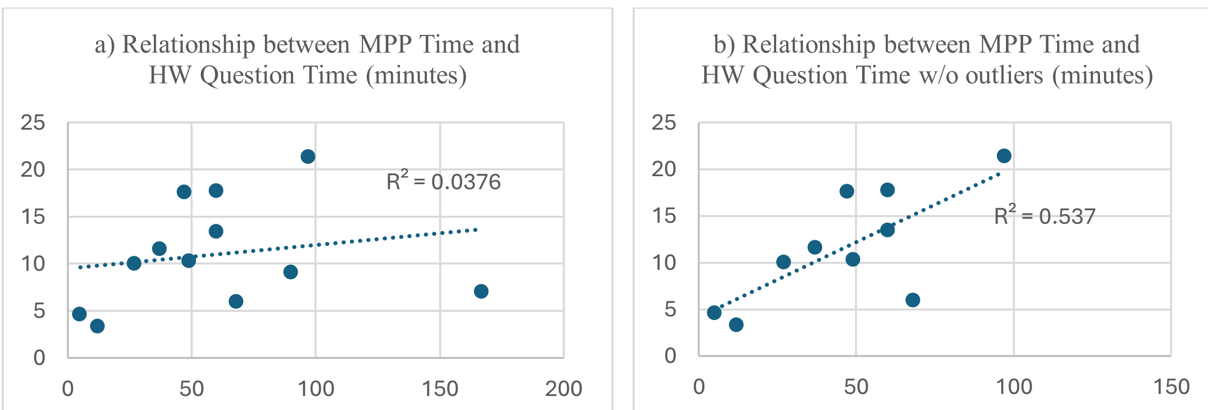

Figure 4: MPP versus Avg HW Question Time a) with (n=12) and b) without (n=10) Outliers

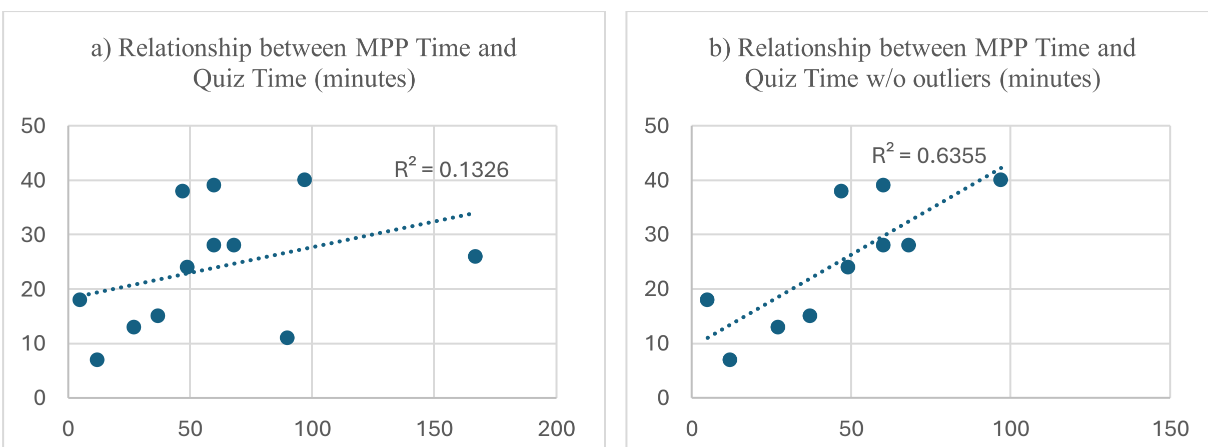

Figure 5: MPP versus Quiz Question Time a) with (n=12) and b) without (n=10) Outliers

MPP Attempts Inversely Correlated to Knowledge?: With most of the students using three or fewer attempts to complete the problem, it is worth looking further into the two students that used more than twice as many attempts. Recall most incorrect answers were to the numerical answer questions, steps 8-11, 16, 17, 20, 21, 23, 24, and 26 and every path the student chose to take would require the completion of those steps. As a result, the two students in question required so many attempts due to their inability to correctly solve those numerical questions and a seemingly strong desire to get 100% on the assignment. While both students were able to successfully complete the problem, this does not appear to translate to improved knowledge related to the MPP concepts, as their quiz and exam question scores were among the lowest of all students. The one exception to this is student 09LT, who was a student that had low participation in the course, having not even taken the exam related to the MPP concepts, and ultimately failed the course. One possible explanation would be that the students were more concerned with getting a good grade rather than fully understanding the concepts, and thus when they were not given unlimited attempts, they were less successful than the students that were able to complete the MPP in fewer attempts.

Other Observations: Finally, one other observation that the authors found interesting was that the standard deviation of the average time spent on EoC HW problems is quite high. The average time spent on a HW question was 10.99 minutes, while the standard deviation was 5.63. The authors knew some students work faster than others, but were surprised by just how much it varied. It should be acknowledged that the data came from the online HW system which only tracks how long students have the browser window set to a given problem, so many other factors may have contributed to this result.

Planned Future Work:

This work-in-progress study was aimed at testing out a new auto-graded problem type that is incorporated into the online system for a commonly used mechanics textbook. The fall 2024 semester was used as a beta test for the instructors to try out one specific problem in their respective dynamics courses to better understand how the students utilized the MPP, identify some initial best practices for how the MPPs could be used, and explore how the MPP and its interface could be improved.

The authors plan to work with additional instructors and the textbook publisher on several activities to further meet these goals beyond the work that was presented including:

- Incorporate a student survey related to their experiences
- Incorporate an instructor survey including adding more instructors to increase the sample sizes
- Assign MPP(s) multiple times throughout the semester to compare how students approach the same problem after first learning the concept, then reviewing for an exam
- Compare student work using MPPs to hand-written work in order to better understand the correlation between using the MPP interface and unprompted hand-written work
- Create an automated visual representation for how students approached the MPP including incorrect answers

While the MPPs were able to provide a valuable additional learning experience for the students and provided the instructors with information related to student work that would only have been available with hand-written work, there exists significant room for improvement in the functionality of the online system. Most notably, the system should be able to provide a quick way to see how a student chose to solve the given problem, as well as a way to show how a group of students progressed through the problem.

Student interactions with MPPs were recorded through McGraw Hill's Connect system, which logs time-on-task data. However, to account for potential confounding variables, additional measures can be considered. First, students were allowed to complete MPPs in non-supervised conditions, meaning distractions or multitasking may have influenced reported engagement times. Second, prior exposure to similar problems was not explicitly controlled; future iterations of this study could incorporate randomized variations to mitigate recall effects. Third, while time-on-task serves as a proxy for engagement, the system does not differentiate between active problem-solving and passive window inactivity. To address this limitation, future studies could incorporate qualitative observations from students and instructors to complement quantitative findings.

The high performance on quiz and exam questions raises the question of whether these assessments accurately measure conceptual mastery. A content analysis of quiz and exam problems reveals that many questions closely resemble homework problems, potentially contributing to inflated scores, although recall 5 additional students were not included as they did not complete the course. To address this, future assessments can be redesigned to introduce novel variations and emphasize problem-solving flexibility over direct replication[7]. Additionally, Bloom's Taxonomy alignment could be used to ensure that assessment questions progressively challenge students beyond rote recall.

To further contextualize findings, a study could incorporate qualitative feedback from students and instructors. Student reflections could be gathered through surveys to assess their perceptions of MPP effectiveness in improving problem-solving skills. Similarly, instructor interviews would provide insights into observed learning behaviors and misconceptions that may not be evident in quantitative data alone. Prior research in engineering education has shown that student engagement with scaffolded problems is influenced by motivational factors[8]; thus, integrating qualitative data would allow for a deeper understanding of how MPPs impact learning motivation and conceptual retention.

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Appendix:

Introduction

Two lifting systems are being considered to bring up 20-kg boxes into a warehouse 4 m above ground level. The first one consists of an inclined conveyor belt that requires 150 W to operate with no boxes on it, at one cycle every 12 s. This conveyor belt (belt 1) has a mechanical efficiency of 82 percent. The second option consists of a shorter, horizontally placed conveyor belt (belt 2) that requires 120 W to operate while dragging a box from left to right in 6 s and a scissor lift that has a mechanical efficiency of 75 percent. The scissor lift needs 2 s to go back to its original position; retracting to its original position does not consume any power, so the lift can be considered as being off for 2 s while it retracts. If the chosen system is to load 10 boxes every minute, which option would result in less energy consumption?

There will only be one box at a time on either conveyor belt option.

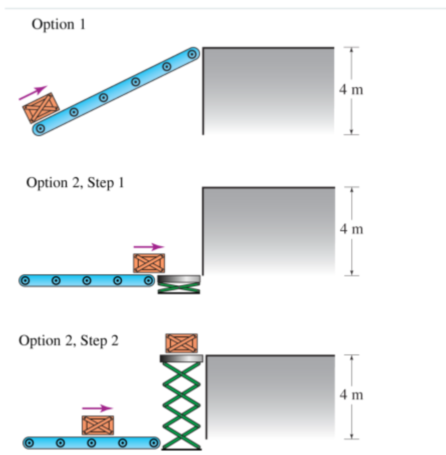

Figure 6: Work, Energy and Power MPP Initial Problem Statement

13.47 It takes 15 s to raise a 1200-kg car and the supporting 300-kg hydraulic car-lift platform to a height of 2.8 m. Determine (*a*) the average output power delivered by the hydraulic pump to lift the system, (*b*) the average electric power required, knowing that the overall conversion efficiency from electric to mechanical power for the system is 82 percent.

Answer

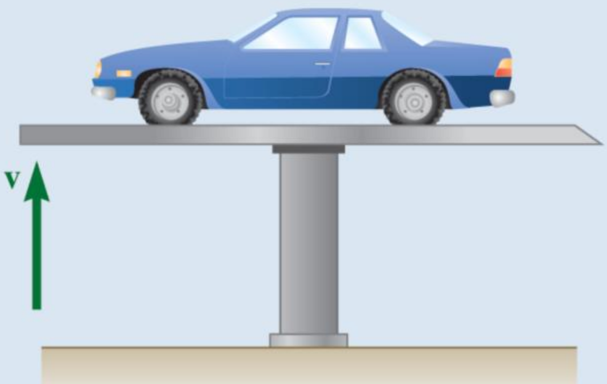

Fig. P13.47

13.51 A 1400-kg automobile starts from rest and travels 400 m during a performance test. The motion of the automobile is defined by the relation $x = 4000 \ln(\cosh 0.03t)$ where x and t are expressed in meters and seconds, respectively. The magnitude of the aerodynamic drag is $D = 0.35v^2$, where D and v are expressed in newtons and m/s, respectively. Determine the power dissipated by the aerodynamic drag when (*a*) $t = 10$ s, (*b*) $t = 15$ s.

Answer

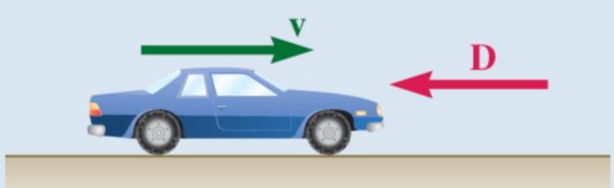

Fig. P13.51

Figure 7: Samples of Assigned Homework Problem Statements

A box is sliding across a surface with an initial velocity v_o = 2 ft/s. The coefficient of kinetic friction is 0.1. The box weighs 100 lbs. A force is applied to the box at the angle shown in the diagram. If the force is defined by the function F(t) = 400 lbf, determine the velocity of the block after it has traveled 5 feet.

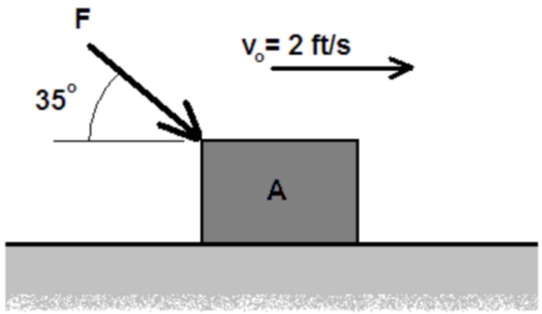

Figure 8: Assigned Quiz Question related to Work

13.191 There has been renewed interest in pneumatic tube transportation systems (e.g., the Hyperloop®). These systems evacuate most of the air from sealed cylinders, and typically the passenger capsules float on air; both of these factors minimize drag. The passenger capsule starts from rest and climbs 1250 feet over a mountain pass. Knowing that the weight of a passenger capsule is 50,000 lb, determine the amount of energy the linear induction motors will need to supply if the capsule is traveling 300 mi/h at the top of the pass.

Answer

Fig. P13.191

Figure 9: Assigned Exam Problem Related to Energy

13.47 It takes 15 s to raise a 1200-kg car and the supporting 300-kg hydraulic car-lift platform to a height of 2.8 m. Determine (*a*) the average output power delivered by the hydraulic pump to lift the system, (*b*) the average electric power required, knowing that the overall conversion efficiency from electric to mechanical power for the system is 82 percent.

Answer

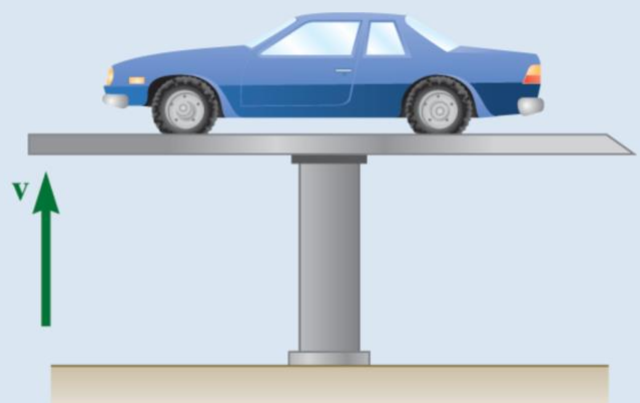

Fig. P13.47

13.48 The velocity of the lift of **Prob. 13.47** increases uniformly from zero to its maximum value at mid-height in 7.5 s and then decreases uniformly to zero in 7.5 s. Knowing that the peak power output of the hydraulic pump is 6 kW when the velocity is maximum, determine the maximum lift force provided by the pump.

Figure 10: Assigned Exam Problem Related to Power (13.48)