# Starting Problems in Mechanical Engineering

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***Abstract*—This Research Work in Progress Paper analyzes the process by which students start solving mechanical engineering problems. Participants of this study were given a problem and asked "what is the first step that you would take?" The participants' first steps to problems were categorized into bins, such as "simple technique" and "complex technique." Problems that had a large starting problem space were chosen, so participants were not confined to one or two solution paths. The performance of undergraduate students, graduate students, and university faculty were compared. Information used from participants responses was used to analyze the relationship between technique used and participant expertise level.**

***Index Terms*—starting problems, problem solving, scaffolding, novice versus expert learning**

## I. Introduction

A student's ability to start solving a problem is important for several reasons. Training students in problem-solving skills helps students gain confidence in their abilities [1] [2]. Ancel found that taking a problem-solving course improved the self-efficacy beliefs of nursing students [1]; Psycharis and Kallia found that taking a programming course improved the mathematical self-efficacy of high school students [2].

The ability to start problems is also beneficial to the trust between teachers and students. According to a professor in the authors' department, if students cannot start problems, they often believe that they are unfairly treated in a class [3]. A large difference in the expectation of difficulty between students and teachers may call into question a teacher's competence and integrity, necessary components of teacher-student trust according to a review performed by Trahan [4].

The problem space of solutions to difficult problems has been analyzed in the cognitive psychology literature [5] [6]. Kotovsky identified three factors contributing to the problem difficulty: learner knowledge, the size of the solution space, and the difficulty of the required representation [5]. Starting problems is a subset of the three factors. More knowledge can help the student choose an effective way to start a problem, while a larger solution space or a difficult problem representation may make it difficult for a student to choose a correct starting step.

The process by which students solve novel problems has also been studied in the context of worked examples [7] [8]. Students often memorize a set of steps or procedures from a worked example without elaboration or connecting to previously existing knowledge. An inability to apply knowledge learned from worked examples can potentially make it difficult for novices to select effective ways to start novel problems.

The pathways taken by novices can be contrasted with those taken by experts. Previous work has been done to understand the characteristics of subject-area experts. A study of geometry students found that skilled problem-solvers focused on key steps and skipped unimportant ones [9]. The problems used in this study contain extraneous information; the problem solver must know what to utilize and what to ignore.

In physics education, Kohl found that experts switched between representations fewer times while solving a problem and finished the problems faster. Even so, novices were just as likely to use multiple representations; they were just less effective at using them in problem solving [10]. This paper focuses on the first representation or the first step; such a focus may shed light on the differences between experts and beginners in more detail.

In mathematics education, Grosse found that instruction in multiple solution methods has benefits, including increased student motivation and increased understanding of each representation [11]. Having multiple options gives the problem solver the ability to choose the approach that is most effective in starting a problem. This paper addresses whether experts are more likely to choose the most effective approach.

## II. Method

### A. Overview

The subject population consisted of undergraduates, graduate students, and professors in the Mechanical Engineering department of the authors' institution. Undergraduates were chosen from the approximately 55 enrollees of Introduction to Engineering Computation, a sophomore and junior level course in Mechanical Engineering. Graduate students were the attendees of a seminar hosted by the Graduate Association of Mechanical Engineers, and professors were chosen by appointment. All participants consented to the study.

The participants in this study were given three problems and asked "what is the first thing you would try to start this problem?" Participants were not required to solve the entire problem. Problems 1 and 2 had a five-minute time limit, and problem 3 had a ten-minute time limit. Undergraduates were given the problems during the recitation period attached to the Engineering Computation class. Graduate students were given the problems during a seminar. Faculty were given the problems by appointment.

Problem 1 provided participants with a table and a graph of data collected from a prosthetic testing context. Participants were then asked to estimate the value of a variable in between data points. Techniques suggested by the participants include reading the graph (least complex), interpolation, and curve fitting (most complex). Responses that did not fit in any of these three categories were classified as "other."

Problem 2 provided participants with equations of a circle and an ellipse and their graphs. Participants were then asked to find the area lying inside both curves. Techniques suggested by the participants included visual estimation (least complex), Monte Carlo method, and integration (most complex). Responses that did not fit in any of these three categories were classified as "other."

Problem 3 provided participants with a simple, rigid-body model of a robot leg. The relationship for hip torque and leg angle was also given. Participants were asked to consider a situation in which the leg can deform. They were then asked to find the hip torque at a given angle for this deformable model. Techniques suggested by the participants included drawing a free body diagram (FBD). Responses were separated by whether an FBD was drawn. If a FBD was not drawn, responses were binned by whether progress was made.

### B. Problems

*1) Problem 1:* A PhD student and her advisor published the graph below of the physiological gait cycle describing position and orientation of an ankle. Lets say that the table below represent the data on the Physiological gait (not the Model). Estimate the y position of the ankle at 34% of the gait cycle.

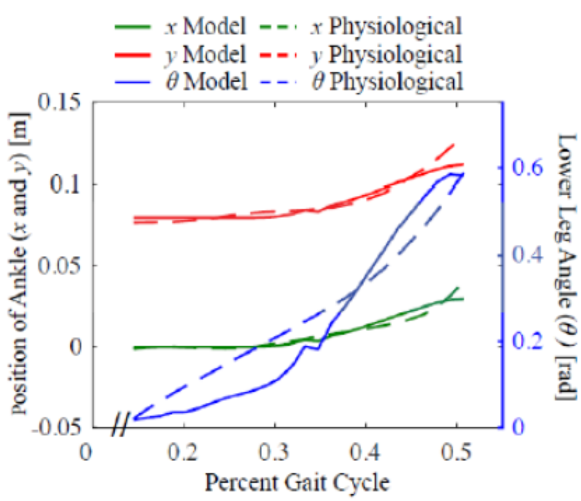


Fig. 1. Problem 1 graph

What is the first thing you can try to start the problem? "I dont know" is a valid response.

| % gait cycle | x (mm) | y (m) | Θ (rad) |
|---|---|---|---|
| 0.15 | 0.0 | 0.080 | 0.06 |
| 0.2 | 0.0 | 0.082 | 0.11 |
| 0.3 | 0.1 | 0.085 | 0.21 |
| 0.4 | 4.1 | 0.089 | 0.37 |
| 0.45 | 11.0 | 0.098 | 0.43 |
| 0.5 | 26.2 | 0.115 | 0.59 |

Fig. 2. Problem 1 data table

*2) Problem 2:* We are interested in the area $A$ that lies inside both the circle of radius 2, centered at (1, 0.5) and the ellipse with equation $\frac{x^2}{25} + \frac{y^2}{4} = 1$.

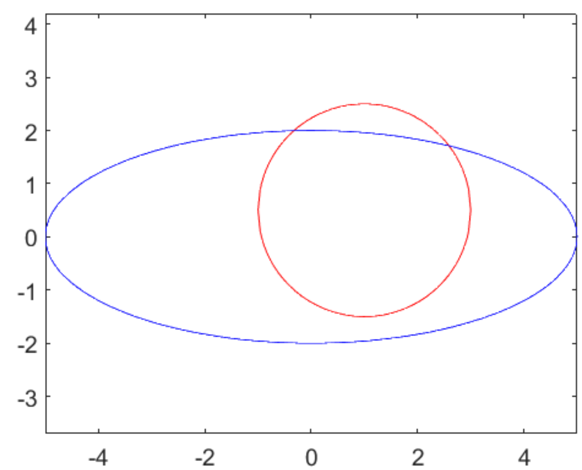

Fig. 3. Problem 2 circle and ellipse

List all the different things you might try to find this area $A$. What is the first thing you would try? "I dont know" is a valid answer.

*3) Problem 3:* A leg for a walking robot is being tested (a). As a rough first estimate, you model the leg as a mass m attached to one end of a rigid stick with length $L$ (b). The assembly is standing up at an angle  to the ground because a hip torque $\tau$ is applied on the end with the mass. The stick does not slide on the ground, but its contact point with the ground can rotate.

Modeling the leg as a rigid stick, you find the following relationship between the applied torque  and the equilibrium angle $\beta$ (Fig. 5).

This is not a bad estimate for rigid legs, but it may be inaccurate if the legs are deformable (as in (a)). If, instead of a rigid leg, the leg is a **compression spring** with spring constant k, **what is the first thing you would do to estimate the torque required to hold the leg at $\beta = 60°$ and why?** Please consider two cases: (1) $\frac{mg}{kL} \ll 1$ and (2) $\frac{mg}{kL} \approx 1$.

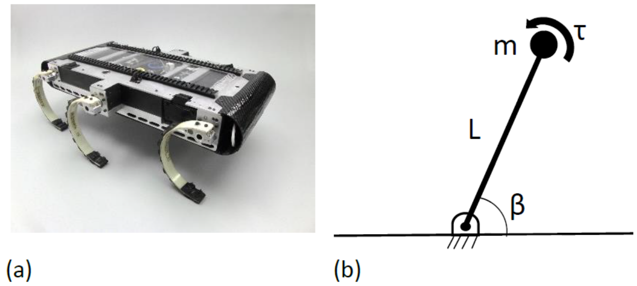


Fig. 4. Problem 3 robot and model

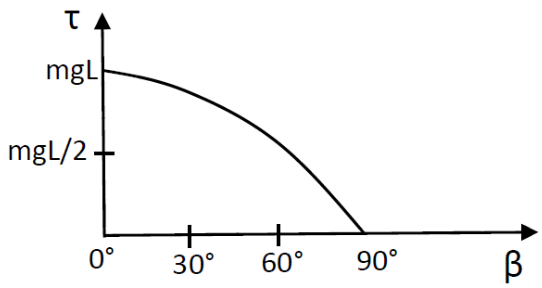


Fig. 5. Problem 3 rigid model relationship

## III. Analysis

The characteristics of how the participants started the problems were studied. Characteristics include (1) techniques used: drawing a free body diagram, finding equations of motion, reading a graph, and suggesting mathematical or computational methods and (2) progress made or result obtained: answer obtained, correct equation of motion stated, or effective technique suggested.

For problems 1 and 2, the technique suggested by the participant was analyzed. If multiple techniques were suggested, the first one written down was used for analysis. If a student wrote "I would try this first...", then this technique was used for analysis.

For problem 3, whether the participant used a FBD was analyzed. If the participant suggest drawing a FBD or drew a FBD, the response was counted. Partially drawn FBDs were also counted. This type of binning was chosen because drawing a FBD is a canonical part of solving statics problems. Participants who did not draw FBDs were further binned into those who made progress and those who did not make progress. Progress was defined as giving a correct torque balance or using the graph for the case $\frac{mg}{kL} \ll 1$.

## IV. Results

The results for problems 1, 2, and 3 are tabulated below.

TABLE I
Problem 1

| **Participants** | ***Graph*** | ***Interp.*** | ***Curve Fit*** | ***Other*** | ***Total*** |
|---|---|---|---|---|---|
| Undergraduates | 6 | 20 | 18 | 7 | 51 |
| Graduate students | 8 | 5 | 2 | 1 | 16 |
| Faculty | 4 | 3 | 0 | 3 | 10 |

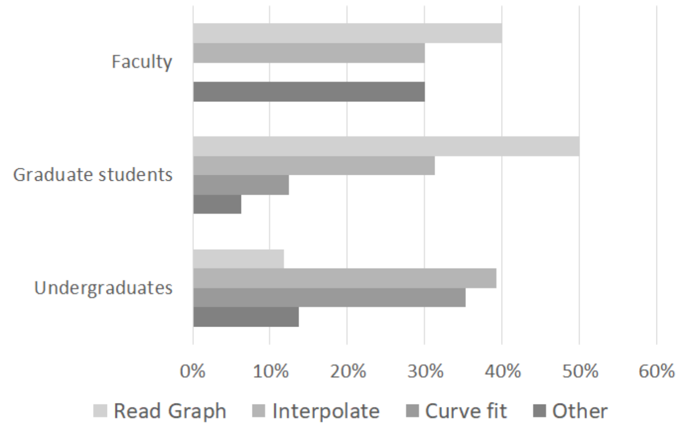


Fig. 6. Problem 1 responses by technique

TABLE II
Problem 2

| **Participants** | ***Visual*** | ***MC*** | ***Integral*** | ***Other*** | ***Total*** |
|---|---|---|---|---|---|
| Undergraduates | 5 | 13 | 16 | 5 | 39 |
| Graduate students | 0 | 0 | 3 | 1 | 4 |
| Faculty | 2 | 1 | 3 | 4 | 10 |

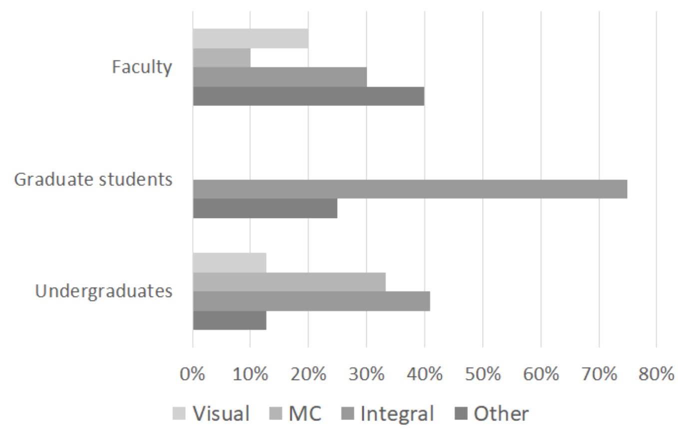


Fig. 7. Problem 2 responses by technique

TABLE III
Problem 3

| **Participants** | ***FBD*** | ***No FBD, Progress*** | ***No FBD, No Progress*** | ***Total*** |
|---|---|---|---|---|
| Undergraduates | 18 | 3 | 8 | 39 |
| Graduate students | 12 | 0 | 0 | 12 |
| Faculty | 5 | 4 | 1 | 10 |

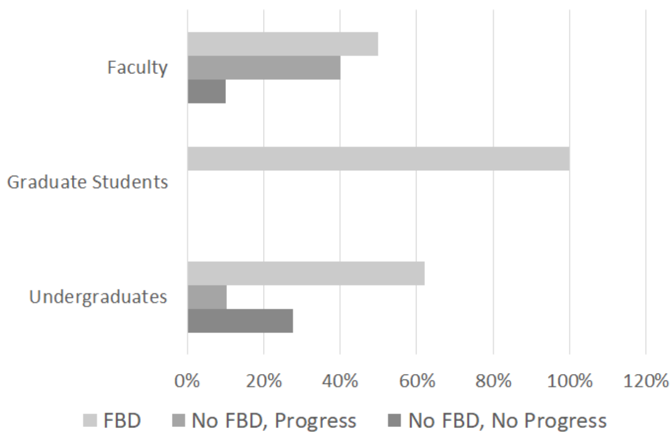


Fig. 8. Problem 3 responses by by whether Free Body Diagram (FBD) technique was drawn

## V. Discussion

The typical problem solving heuristic is to first try a simple technique to get a rough approximation, followed by a more complicated method if more accuracy is needed.

During the PhD oral qualifying exams at the Authors' institution, it has been said that students who ignore simple approaches and begin problems with a complex method make the graders uneasy, because it is not clear these students understand the problem [3].

The problem 1 results suggest that graduate students and faculty prefer a "faster" or "simpler" technique as the first step to solving the problem. That is, graduate students and faculty tended to suggest reading the graph instead of interpolating or doing a curve fit. More than 40% of faculty and graduate students chose to read the graph for problem 1, compared to only 12% of undergraduates. All three faculty whose responses fit into the "other" category corroborated the data and the graph as a first step. This cross-checking approach was not used by undergraduates and graduate students.

The problem 2 results show that about 35% of undergraduate students mentioned Monte Carlo (MC), none of the graduate students mentioned MC, and one of the of ten professors mentioned MC. Professors tended to avoid the most complex route as the first step. Of the professors who used an "other" method, one suggested a simple geometric approach and another suggested to cut and weigh the desired shape; both of these relatively "simple" techniques. Seven of ten professors avoided integration, which is the most complex way to solve this problem. It should be noted that MC is a technique that is emphasized in the Intro to Engineering Computation class. All of the students have had some exposure to MC, and two of the ten professors surveyed are present or past instructors of this class. However, none of the graduate students have had recent experience with MC.

The problem 3 results show that compared to undergraduates, graduate students were more likely to draw a free body diagram. Five of ten faculty drew free body diagrams. Of the five faculty who did not draw a free body diagram, four were still able to make progress by giving correct approaches. Of the eleven undergraduates who did not draw free body diagrams, only three were able to make progress.

It was found that while a novice may know how to apply a relatively complex technique (e.g. doing a curve fit in problem 1), they may not be adept at choosing among multiple approaches of varying complexity. Engineers of greater experience were able to find the "simple" approaches; this ability may reflect their higher level of sophistication in applying engineering reasoning.

## VI. Future work

This work could be improved by scaling up the study. A larger set of problems may reveal clearer patterns in the difference between novice and expert problems solvers. Furthermore, participants could be selected from other institutions. Students and faculty at the authors' institution, which were exclusively used for this study, may not be representative of engineering schools across the world.

Another potential approach is to improve the experimental setup. Other data-gathering methods, such as interviews and videotaping, could be used. This may reveal more about a participant's problem solving process, beyond their written response. Furthermore, the method of coding a participant's data could be improved to better describe the actions and steps they took.

A third potential direction is to change the problems themselves to better challenge participants' abilities. These problems could be made similar to open-ended research problems instead of homework problems. Care must be taken, however, to ensure that participants understand the problems they are solving.

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