Work in Progress: Initial Approaches for Starting Open-Ended Problems in Mechanical Engineering

Hao Li, Massachusetts Institute of Technology

Hao Li is currently a PhD student studying Mechanical Engineering at MIT. He earned his Bachelor's degree from Rice University.

Anette Hosoi, Massachusetts Institute of Technology

Anette (Peko) Hosoi is Associate Dean of Engineering and the Neil and Jane Pappalardo Professor of Mechanical Engineering, at MIT. She received her PhD in Physics from the University of Chicago and went on to become an NSF Postdoctoral Fellow in the MIT Department of Mathematics and at the Courant Institute, NYU. She is a leader in the study of the hydrodynamics of thin fluid films and in the nonlinear physical interaction of viscous fluids and deformable interfaces. Her work spans multiple disciplines including physics, biology and applied mathematics, and is being used, in collaboration with Schlumberger-Doll Research, Bluefin Robotics, and Boston Dynamics to guide the engineering design of robotic crawlers and other mechanisms.

Prof. Hosoi is an exceptional, innovative teacher and an inspiring mentor for women in engineering. She was awarded the Bose Award for Excellence in Teaching, and a MacVicar Fellowship.She is a recipient of the 3M Innovation Award and has held the Doherty Chair in Ocean Utilization at MIT. She is a Radcliffe Institute Fellow and a Fellow of the American Physical Society. Her research interests include fluid mechanics, bioinspired design and locomotion, with a focus on optimization ofcrawling gastropods, digging bivalves, swimming microorganisms and soft robotics. Prof. Hosoi is also an avid mountain biker and her passion for sports has led her to create MIT Sports Lab, a program that is designed to build an interconnected community of faculty, students, industry partners, alums and athletes who are dedicated to applying their technical expertise to advance the state-of-the-art in sports.

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Hao Li (wl11@mit.edu) and **Anette Hosoi** (peko@mit.edu)
Department of Mechanical Engineering
Massachusetts Institute of Technology

Introduction

Much work has been done studying problem solving from beginning to finish [1] [2] [3], but little focus has been placed on the beginning of a problem, at least in the non-design mechanical engineering curriculum. How a student starts a problem may have significant effect on their ability to fully carry out the solution. A student may solve the wrong problem, spend all their time pursuing the wrong approach, or forget their goal if they do not properly define the problem and formulate a plan [4].

Kohl's work on representations in Physics is related because it shows differences in how novices and experts solve problems [1]. The difference is that novices tend to use more representations and switch between them more often. Experts tend to use fewer representations and solve the problem in a more straightforward way. This work will focus on the first representations used by experts and novices.

Previous work has been done in starting design problems. Yang et. al. studied the relationship between early stage design activity and design outcome. Aspects of design such as sketching, dimensioned drawings, prototyping, designer experience, and time spent were correlated with design success [5] [6]. It was found that simpler prototypes and spending more time on prototyping were correlated with better design outcomes [5]. Elements of starting design problems, such as sketching and prototyping, have analogues in starting non-design problems, such as estimation [7], computation, and closed form solutions.

The start of a problem can be defined. A survey of problem solving strategies was performed by Woods [8]. The process was divided into seven stages: Can do, Define, Explore, Plan, Execute, Check, and Generalize. Of these, the Define, Explore, and Plan stages are the start of the problem. These steps represent the stages before a student commits to a solution path. In the context of engineering education, where the problems used are often well defined, research focus can be placed on the Explore and Plan stages.

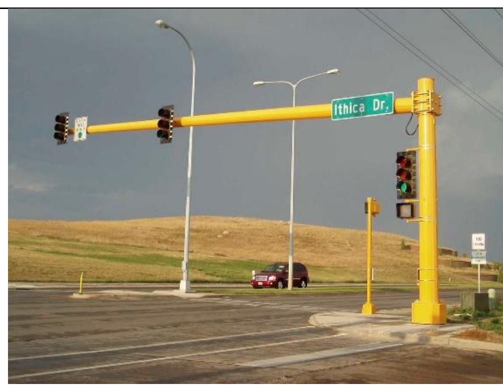
Open-ended problems can be defined in the context of education. The problems used for engineering education can be divided into two categories. The first category is open problems, which can have multiple solution methods, multiple solutions, and possibly incomplete information. The second category is closed problems, which usually have one solution path. A classification of open-ended and closed problems used in mathematics education was proposed by Maker [9]. Her work divides the open-closed problem continuum into six gradations, I through VI, representing increasingly open-ended problems. Type III and IV problems are of interest because they are open-ended enough to have multiple solution methods but not so open-ended as to be intractable for analysis.

	Simple, closed problem	Open-ended problem
Design curriculum example	Use the mill to make a simple part	Design a product to perform a task
Non-design curriculum example	Solve a problem using a law or formula	**Formulating a model to describe experimental data**

Table 1: Examples of open-ended and closed problems: the focus of this paper is open-ended problems in the non-design mechanical engineering curriculum.

This paper is the extension of an earlier work on starting problems by the authors. In this earlier work, a student was given a problem and asked to provide what they would do as a first step. Techniques were problem specific and were roughly binned into “simple technique” and “complex technique,” representing what the authors believed were solutions that required different levels of effort and time. It was found that more experienced problem solvers tended to use simpler techniques to start, suggesting more sophisticated application of engineering reasoning. This paper extends the previous work by applying definitions to more accurately describe the start of a problem [10]. We state the following research questions:

RQ: Are there initial approaches to starting a problem that are more likely to get the problem solved?



You work at an engineering design company, and your supervisor has given you the following project:

A horizontal cantilevered beam is used to support traffic lights as shown. For the horizontal part of the beam, several designs are possible:

1. Circular cross-section with radius 5cm at the fixed end (where it’s attached to the vertical pole) tapering to a circular cross section with radius 10cm at the free end
2. Circular cross-section with radius 10cm at the fixed end tapering to a circular cross section with radius 5cm at the free end
3. Circular cross section with radius 7.5cm throughout the beam
4. A different design

You will need to find the best design and **justify it with reasoning**.

Figure 1: Problem used for this study

Method

The participants were 69 students recruited from an undergraduate Mechanics of Materials course. The participants were given 15 minutes to solve a problem. The made two submissions: one with the prompt "How would you start solving this problem?" at 5 minutes and another with the prompt "Solve as much of the problem as you can" at 15 minutes. These problems are somewhat open-ended and have multiple solution paths. Specifically, the problem in Figure 1 was used. Participants were prompted to explore the problem space, and were discouraged from erasing any ideas or approaches they wrote down. Participants were not required to finish the problem, though it is possible to obtain an answer within 15 minutes. Students did not provide their names on submissions. The type of technique the participant used will be analyzed relative to their progress in solving the problem.

Results and Analysis

Based on previous work by the authors, it is expected that students will use one of several approaches to solve each problem. These approaches will depend on the problem given [10]. For the problem given in Figure 1, a correlation will be performed between participants' 5 minute and 15 minute responses. The 5 minute "starting approach" response was analyzed by the presence or absence of one of five characteristics. These five characteristics are: free body diagram or drawing, use of calculations or analysis, intuition or estimation, identification of additional background, and consideration of alternative designs. The coding of student responses is described in more detail in Table 2. These five characteristics, while specifically selected for this problem, are general enough to be applicable to other engineering problems as well. The 15 minute "solution" response was binned by two items: the presence of an answer and whether the answer was the preferred choice. For the problem given in Figure 1, a choice of design 2 or 4, accompanied by the appropriate justification, was considered the preferred choice.

For each of the five problem-starting characteristics described above, the students were divided into two categories: those whose response contained the characteristic and those who did not. It was possible for a student's 5 minute response to contain more than one characteristic. For each of the two solution outcomes described above, the students were divided in two categories of participants: those who were successful and those who were not. For each pair of starting characteristic and solution outcome, the chi-squared test was used to determine whether the relationship was due to random chance. The p-values are given in Table 3. A p-value of less than .05 was considered statistically significant.

Characteristic present in 5 minute submission	Example keywords
Free body diagram (FBD) or drawing	Draw, diagram, moment and shear diagram
Analysis or calculation [10]	Solve, calculate, find, optimize, minimize, Solidworks, moment and force balance
Intuition or estimation	Approximation, estimation, elimination of choices with reasoning
Identification of add'l info	Cost, building standards, material properties, wind loads
Alternate design	Alternate design, advantages of alternate design

Table 2: Characteristics of students' 5 minute submission

Characteristic present in 5 minute submission	p-value, chi-squared test vs. answer is choice 2 or 4	p-value, chi-squared test vs. answer present	Correlation direction
FBD or drawing	.848	.866	Neutral
Analysis or calculation	**.035**	.056	**Negative**
Intuition or estimation	.078	.142	**Positive**
Identification of add'l info	.600	.260	Slightly positive
Alternate design	.720	.141	Slightly positive

Table 3: p-values of characteristics vs. problem solving outcome

Discussion

The presence of analysis or calculation in the 5 minute response had a negative relationship with outcome in the 15 minute response. We find statically significant p = .035 for the outcome indicator of obtaining the preferred answer, and p = .056 for the outcome indicator of obtaining an answer at all. Participants preferring analysis or calculation tended to "dive in" to solving the problem analytically, often running out of time.

On the other hand, the presence of intuition or estimation in the 5 minute response had a positive relationship with outcome in the 15 minute response. We find p = .078 for the outcome indicator of obtaining the preferred answer, and p = .142 for the outcome indicator of obtaining an answer at all. This result is not statistically significant, but it does suggest that students using intuition obtained a result more often than students who did not. Participants using intuition tended to "cut through" the difficulty of detailed analysis and obtain an answer within the time limit. The other three categories had relatively weak relationships with outcome. This data suggests that for relatively open-ended problems, it may be advantageous for students to use their intuition or do an estimation first, and then follow up with detailed analysis.

Next Steps

Further analysis can be done to better understand why students who started with analysis or calculation tended to obtain an answer less often, and why students who started with intuition or estimation tended to obtain an answer more often. Additionally, this experiment can be repeated with a different problem to determine if the result is repeatable. Finally, the experiment can be performed on more experienced problem solvers such as graduate students and faculty. Care would be taken to ensure that the experimental conditions are controlled as much as possible among the different types of participants.

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