

Characterization of Problem Types in a Statics Textbook

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Abstract— In this Work in Progress Research paper we present preliminary results on analysis of the problems present in a common engineering textbook. In order to transition students from novice to expert problem solving, they must have practice solving problems that are typical of engineering practice, i.e. ill-structured and complex. While it is generally believed that classroom problems are for the most part closed-ended and not complex, there is no work in the literature to confirm this belief. In order to address this gap, we analyzed the types of problems present in a commonly used statics textbook, using Jonassen’s well-known typology. Our findings show that almost all of the problems are algorithmic, with a few rule-based and story problems. There were no problems with higher levels of ill-structuredness, such as decision-making, diagnosis-solution, or design problems. Some educators may believe that because statics is an introductory level class, it is appropriate to only present well-structured problems. We argue that it is both possible and necessary to include ill-structured problems in classes at all levels. Doing so could potentially support students’ critical transition from novice to expert problem solvers.

Keywords—*problem solving, statics, ambiguity*

I. INTRODUCTION AND BACKGROUND

Problem solving is considered to be a central activity of engineering. Professional engineering practice involves solving problems that are ill-structured, complex, and that often have multiple paths to a correct solution. The importance of developing skills to successfully address ill-structured problems has been widely recognized by both engineering educators and accreditation agencies for engineering programs.

It is generally recognized in the literature that workplace and classroom problems are qualitatively different in character. Jonassen, Strobel, and Lee found that one of the primary characteristics of workplace problems is that they are ill-structured [1]. Regarding the difference in structure between classroom and workplace problems, Sheppard et al. argued that “Solving right-answer problems is not necessarily problem solving: the problems that students are typically asked to solve do not build the kind of problem-solving skills they will need later in their program or in practice” [2] (p. 48). Our own work has found that students believe there is a difference between

workplace and classroom problems, with classroom problems being less complex, more constrained, and focused on a single topic [3].

In addition to differences in problem structure, there are differences in the ways students and practicing engineers solve problems. Novices and experts think about their disciplines differently when solving problems [4-6]. It has been shown that domain expertise is a significant predictor of problem-solving performance in sports, chess, medical diagnoses, attorney’s decision making, math learning, architecture, and electrical engineering (see e.g., Refs. [7, 8]). Experts also perform tasks in a qualitatively different way than novices. They can create representations of the problem space more easily [5], have complex schemata that can guide problem interpretation and paths to solving [5], and are less affected by working memory demands [9]. With regard to engineering problem solving engineers tend to be more reflective, actively frame the problem in order to direct the search for potential solutions, are solution focused as opposed to problem-focused, and tend to make frequent switches between different cognitive activities [10-17].

Surprisingly, there has been little work to actually analyze the types of problems typically solved by engineering students. Most of the work on engineering problem solving in the classroom has focused on design problems and problem-based learning. For example, people have studied how students experience design and other ill-structured problems [18, 19], described various approaches to problem-based learning [20, 21], and presented instructional strategies to support problem solving [22]. However, we have been unable to find any systematic, empirical studies that analyze typical homework problems or problems in textbooks. We argue that, except in unusual cases, students are not habituated to solve the problems typical in design or problem-based learning courses. Instead, they learn that engineering problem solving involves the kinds of problems they are assigned for homework, which are often the end-of-chapter problems in their textbooks. If, as has been described, these problems are simple, well-structured, and unambiguous, it is no wonder that there is a disconnect between academic preparation and the needs of the workforce. However, empirical evidence is needed to ascertain if the majority of problems students solve are in indeed simple, well-structured,

and unambiguous. Thus, the research question we seek to answer is: What are the types of problems present in engineering textbooks?

II. METHODOLOGY

A number of classifications and taxonomies of engineering problems exist, typically classifying problems on a range from completely defined to highly ambiguous. The most well-known typology of problems comes from Jonassen and his collaborators [23-25]. They classified problems into 10 (originally 11) types, ranging from algorithms to dilemmas.

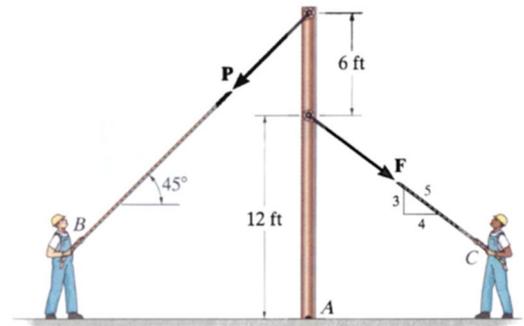
We used Jonassen's taxonomy to classify the problems in a common statics textbook [26]. Table I lists the problem types in this taxonomy. These problem types form a continuum from most well-structured (algorithmic) to most ill-structured (dilemmas). Initial classification on a subset of problems was done by the 2nd and 4th authors, and then reviewed by all four authors. Once the classification of these problem was agreed upon, the 2nd author classified the remaining problems in the textbook.

III. FINDINGS

Out of 853 total problems, there were only four story problems and four rule-using problems, with the remainder (845) being algorithmic. Figs. 1-3 provide examples of each of these types of problems.

TABLE I. Problem types, from Refs. [23, 24].

Problem Type	Description
Algorithmic	Apply a procedure to a problem with the procedure given or evident in the problem
Story	Select and apply correct procedure to a problem presented as a story
Rule-using	Apply rules to a constrained system with finite rules
Decision-making	Make a decision in a situation with limited alternatives
Troubleshooting	Examine and evaluate a malfunctioning system with one or more faults
Diagnosis-solution	Diagnose a complex system with faults and several possible solutions
Strategic performance	Meet goals in a complex system
Case/policy analysis	Develop a solution for a complex system with multiple ill-defined goals
Design	Produce an artifact based on a vague goal statement with few constraints
Dilemmas	Develop possible approaches to a situation with no definitive solution and irreconcilable perspectives

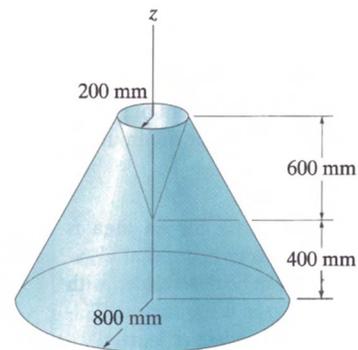


Two men exert forces of $F = 80$ lbs and $P = 50$ lbs on the ropes. Determine the moment of each force about A. Which way will the pole rotate, clockwise or counterclockwise?

Fig. 1. Example of a story problem.

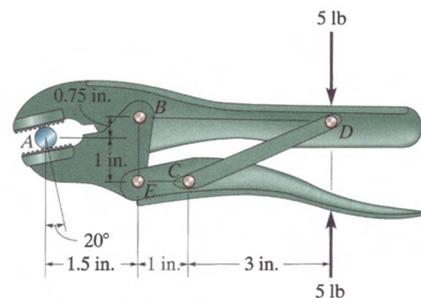
If A, B, and D are given vectors, prove the distributive law for the vector cross-product, i.e. $\mathbf{A} \times (\mathbf{B} + \mathbf{D}) = (\mathbf{A} \times \mathbf{B}) + (\mathbf{A} \times \mathbf{D})$

Fig. 2. Example of a rule-using problem.



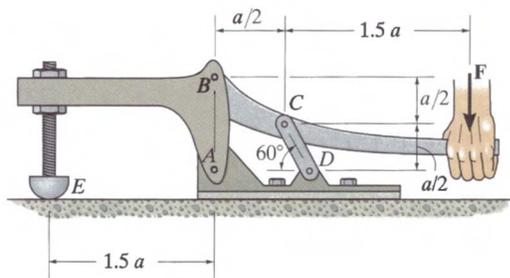
Determine the moment of inertia I_z of the frustum of the cone which has a conical depression. The material has a density of 200 kg/m^3 .

Fig. 3. Example of an algorithmic problem.



A 5-lb force is applied to the handles of the vise grip. Determine the compressive force developed on the smooth shank A at the jaws.

Fig. 4. Algorithmic problem with no embodiment.



The toggle clamp is subjected to a force F at the handle. Determine the vertical clamping force acting at E .

Fig. 5. Algorithmic problem with embodiment.

Even if two problems are uniquely classified as algorithmic, they may not present the same cognitive difficulty. Consider the problems shown in Figs 4 and 5. These problems present nearly identical concepts, and would be solved in a similar way. However, the problem in Fig. 5 has the additional feature of a hand manipulating the clamp. Research in the area of embodied/grounded cognition [27, 28] has demonstrated a strong link between our motor processes (e.g., our experiential connections of using one's hand) and understanding the underlying cognitive processing [29]. According to an embodied view of cognition, observing the hand in Fig. 5 would facilitate understanding of the problem space, as compared to the isolated view presented in Fig. 4 [30, 31].

IV. DISCUSSION AND FUTURE WORK

This work provides the first empirical study of the types of problems found in engineering textbooks. Consistent with discussion in the literature [1-3], we have found that almost all of the problems in a common statics textbook [26] are algorithmic. In addition, all of the problems are at the well-structured end of Jonassen's taxonomy. There are no problems that could be considered ill-structured.

Our findings are necessarily limited, as they are based on analysis of a single textbook from a class that appears early in the engineering curriculum. It is quite possible that textbooks for classes appearing later in the curriculum would contain problems that tend towards being more ill-structured. Nevertheless, these findings have significant implications for engineering teaching. Studies of engineering practitioners have shown that in a wide variety of settings they regularly encounter problems that are ill-structured and complex, often with conflicting goals and constraints, multiple acceptable solutions, and ill-defined success criteria [1, 32-34]. For students to transition from novice to expert, they need to be exposed to the real-world practices of engineers. Most engineering schools recognize this need, and provide students with early exposure through freshman design classes. However, use of well-structured problems in core engineering classes may habituate students to solving problems that are not representative of engineering practice. We argue that it is possible to create ill-structured problems even in an early course such as statics. For example, consider the following problem:

Design a truss bridge that will withstand the load of a single full tractor-trailer truck. The maximum allowed load on any single member of the truss is 350 kN.

This is a design problem (vague goals, few constraints) that requires no more knowledge than would be expected from a statics class.

Although Jonassen's typology has provided a useful way to classify the problems, we have also noted some important limitations. His typology does not distinguish between similar problems with and without embodiment. Students' ability to solve problems may be affected by these types of cues in the problem statement. Therefore, we intend to revise the coding scheme to account for these differences. This revised coding scheme will not only be used to classify problems in additional statics textbooks as well as textbooks for upper level engineering classes. The coding scheme will also allow us to design experiments in which we manipulate the way in which problems are presented.

V. CONCLUSIONS

This paper presents the first analysis of the types of problems present in an engineering textbook. We found that almost all of the problems in a commonly used statics textbook are algorithmic, with no problems that could be considered ill-structured. The lack of ill-structured problems is a missed opportunity to help students transition to expert problem solvers. We argue that it is important for students to experience ill-structured problems in all classes, including introductory ones such as statics. Habituating students to solve ill-structured problems will better prepare them to think like engineers.

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