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Characterization of Problem Types in Engineering Textbooks

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Abstract

Engineering problems have been generally classified as either ill-structured or well-structured. Various authors have identified the characteristics of ill-structured problems or presented typologies of problems. Simple definitions state that well-structured problems are simple, concrete, and have a single solution, while ill-structured problems are complex, abstract, and may have multiple possible solutions. It is commonly understood that classroom problems are well-structured while workplace problems are ill-structured. However, we cannot find any empirical data to confirm or deny that the bulk of classroom problems are well structured. This work-in-progress (WIP) paper specifically examines the types of end-of-chapter problems present in the two most commonly used statics textbooks. Our data reveal that nearly all of the problems across these two textbooks were well-structured. We argue that even in foundational courses such as statics, students should be exposed to ill-structured problems. By providing opportunities for students to solve more ill-structured problems, students can become more familiar with them and become better prepared for the workforce.

Introduction

Successful problem-solving has been described as a core disposition critical in both learning about and practicing engineering [1]-[3]. However, researchers often note substantial differences in how problem-solving is actualized in the workplace and academic settings. Professional engineers solve problems that are characterized as complex, not providing all information necessary, not providing an established choice-set, having multiple correct solutions, and may require expressing personal opinions about problem elements [2], [4]-[6]. Engineering problems that have these characteristics occur in the workplace and are commonly referred to as ill-structured or open-ended. Researchers have identified a broad range of ill-structured problems solved by practicing engineers and how they solve these problems [2], [7]-[11]. Thus, we now have a literature base exploring ill-structured problems and problem solving in engineering practice.

In contrast to engineering workplace problems, problems presented in the curriculum (classroom, homework, and exams) are presumed to be well constructed, simple, concrete, and require a single answer [2], [12]. Engineering problems that have these characteristics occur in schools and universities and are commonly referred to as well-structured or transformation problems [13]. However, we have struggled to find empirical research either confirming or denying these characterizations of academic problems within contemporary engineering instruction. To our knowledge, no recent research has specifically surveyed or categorized the types of problems engineering students routinely encounter in their coursework. Consequently, this work in progress research paper considers the question, ***what kind of problem types are engineering students most likely to encounter in a statics course?***

Students express strong opinions about the perceived disconnect between their engineering education experience and the practice of engineering-- through interviews, think-aloud protocols, and self-reports [14], [15]. Students believe that classroom problems are less complex, more constrained, and often limited to a single topic when compared to their workplace complements [15]. Students also believe that incorporating real work examples into coursework would greatly enhance the quality of their education [16]. To empirically document this perceived disconnect, we employed Jonassen's [1, 2] and Jonassen and Hung's [17] problem typology. In this typology, problems are grouped into eleven categories, ranging from well-structured (e.g., logic or algorithmic) to ill-structured (e.g., design problems and dilemmas). It is important to note that Jonassen considered his typology to also be taxonomic (i.e., problem-solving that is less complex/well-structured builds skills that are required to solve problems that are more complex/ill-structured) [1].

A final aspect of engineering problems we wished to investigate (not explicitly present in Jonassen's typology) relates to the presence or absence of modeling and the form that problem solutions take. Four kinds of solutions were documented in our analyses: numerical, expression, model, and qualitative. Finding a larger proportion of qualitative answers (compared to numerical, expression, or model) may be predictive of a larger proportion of complex and ill-structured problems.

Methods

To assess the types of problems engineering students habitually solve, we surveyed problems presented in two of the most commonly used statics textbooks, the ones by Hibbeler [18] and Beer, et al. [19]. These textbooks were chosen as being the most commonly used for this topic. We used Amazon sales rank as a proxy for market share; market-share data is not publicly available. We balanced our sample to consider the goal of our research: what are students most likely to see throughout an entire course in statics? A course typically draws from a single textbook. While we could have selected more textbooks and smaller samples (i.e., a few chapters across more textbooks), this would give us more information on how topics differ across textbooks, rather than how generally students experience course problems across an entire course. That is, we would be measuring differences in specific topics in statics, rather than statics as a whole as students experience it. Thus, we opted to categorize all problems in these two textbooks rather than random sampling across more textbooks. We categorized all of the end-of-chapter problems from each textbook. Problems were categorized using Jonassen's typology, the presence or absence of modeling, and the form the solution required.

The third and fourth authors conducted all of the problem classifications. They first conducted an initial classification on a subset of problems (i.e., two chapters), and this classification was reviewed by all authors for conceptual agreement. Upon reaching a consensus, one researcher coded the even-numbered problems and the other coded the odd-numbered problems. After finishing each chapter, the coding authors would review the problems together and discuss any disagreements (and bring them to the larger group as needed). After coding was complete, the results were combined and are represented in Tables 1 and 2. Interrater reliabilities were high, 100% for problem type, 95% for modeling, and 95% for solution type.

The taxonomy for problem type was based on Jonassen's 11 problem types [1]. Jonassen's taxonomy categorizes problems based on numerous criteria including the abstractness and structuredness of the problem. To determine the problem type, the inputs and success criteria were analyzed and compared to Jonassen's taxonomy. For example, logic problems had a limited number of variables that are manipulated while problems that required formulas or procedures to be followed to solve for a specific value fell into the algorithmic category.

In addition to the problem type, the presence or absence of modeling and the required solution format were also recorded. There were three different levels of modeling: no modeling was required, modeling was optional, and modeling was required for the problem. Modeling typically took the form of a free body diagram. If the problem included a diagram with the forces already drawn then no modeling was required by the student. If a model, such as a free-body diagram, would help solve the problem it was coded as modeling optional. However, if the problem specifically asked the student to include a diagram, then it was coded as required modeling. Finally, solution type refers to the form that the answer needed to be in to be considered correct and complete based on the textbook's answer key. Four kinds of solutions were documented: numerical, expression, model, and qualitative.

Findings

Tables 1 and 2 present the problem categorizations for each textbook. Our results revealed a remarkable homogeneity of a single problem type: algorithmic. Specifically, 98.5% and 99.3% of the end-of-chapter problems were categorized as algorithmic for the Hibbler and Beer texts, respectively. All other problems were characterized as logic problems. Algorithmic and logic problems are not only both well-structured problems, they are also the most basic problem types according to Jonassen's typology. The bulk of problem solutions was categorized as numeric, required 80.1% of the time across both texts. Qualitative solutions, indicative of a complex or ill-structured problem, were infrequent. In the Hibbeler text, qualitative solutions accounted for less than 1% of solution types, in the Beer text, it was 3%. The only clear difference between the texts was that Hibbler required slightly more modeling than Beer.

Table 1: Total number and percentages of the different problem elements in Hibbeler [18].

Label	Total	Percentage
Problem Type		
Logic	21	1.45%
Algorithmic	1426	98.%
Modeling		
No modeling	111	7.29%
Modeling is optional	758	49.80%
Modeling is required	653	42.90%
Solution Type		
Numeric	1269	83.38%
Expression	124	8.15%
Model	118	7.75%
Qualitative	11	0.72%

Table 2: Total number and percentages of the different problem elements in Beer, et al. [19].

Label	Total	Percentage
Problem Type		
Logic	13	0.67%
Algorithmic	1927	99.33%
Modeling		
No modeling	378	19.48%
Modeling is optional	1430	73.71%
Modeling is required	132	6.80%
Solution Type		
Numeric	1492	76.91%
Expression	316	16.29%
Model	72	3.71%
Qualitative	60	3.09%

Discussion and Conclusion

These preliminary findings provide clear evidence that end-of-chapter problems for two commonly used statics textbooks are overwhelmingly algorithmic: well-structured, simple, concrete, often requiring a single answer [12]. This may seem obvious to some, that textbooks would have a homogeneous problem structure, but we know of no other research that has empirically documented this assumption. Problem solutions were heavily skewed towards numeric solutions, with less than 3% requiring a qualitative response. In sum, our data confirm the common assumption among researchers (and student perception) that there is a marked difference between the problems that engineering students see in academic settings and those that engineers face in the workplace [15, 20].

Previous research has documented the strong influence that textbook example problems have on students' problem-solving strategies [21, 22]. If instructors only assign textbook problems, students may not have much exposure to ill-structured problems during their statics courses, consequently affecting how well they approach these problems. One of the barriers to incorporating more ill-structured and open-ended problems may be the maxim that students first master the fundamentals. This view is explicit in Jonassen's typology (i.e., simpler problem solving is the building block for more complex problem solving). However, there is emerging empirical evidence that when building students' domain knowledge, engaging students in higher-order retrieval practice is more effective than simpler fact-based retrieval practice [23].

While this particular work focuses on engineering statics textbooks, commonly a second-year foundational course, we argue that engineering students should have the opportunity to solve ill-structured problems early in their academic careers. With internships becoming more popular early in students' academic careers, students are often faced with ill-structured problems before they graduate. By providing added opportunities for students to solve ill-structured problems students can become more familiar with them and become better equipped for the workforce.

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