Characterization of Problem Types in a Statics Textbook

Elliot P. Douglas
Dept. of Enviromnental Enginee1ing Sciences and Dept of Enginee1ing Education
University ofFlo1ida
Gainesville, FL, USA
edouglas@ufl.edu

Nicole Goetz
Dept. of Industtial and Systems Engineering
University of Florida
Gainesville, FL, USA

David J. Theniault
School of Human Development and Organizational Studies in Education
University of Florida
Gainesville, FL, USA

Marah B. Beny
Dept. of Envirolllllental Enginee1ing Sciences
University ofFlotida
Gainesvlile, FL, USA

***Abstract-* In this Work in Progress Research pape1· we prese nt pn liminar y results on analysis of the prnblems 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 enginee1ing practice , i.e. ill-**structuredand complex. While it is genernlly believed that classroom problems are for the most part closed-ended and not** complex, there is no work in the literature to confu•m thi s belief. In 01·der to addr ess this gap, we analyzed the types of problems **present in a commonly used statics textbook, using Jonassen's well-known typology. Om· fmdings show that almost all of the problems are algorithmic, with a few rule-based and sto11'** problems. There we1e no problems with higher levds of ill-**structuredness, such as decision-making, diagnosis-solution, or design prnblems. Some educators may believe that because statics** is an introdu cto11' level class, it is approp1iate to only present well-structured problems. \Ve argue that it is both possible and **necessary to include ill-structm·edprnblems in classes at all levels. Doing so could potentially suppo11students' critical transition from novice to expert problem solvers.**

Keywords-problem solving,statics, ambiguity

I. INIRODUCTION AND B ACKGROUND

Problem solving is considered to be a central activity of engineering. Professional engineering practice involves solving problems that are ill-st:mctured, complex, and that often have multiple paths to a cmTect solution. The impmtance of developing skills to successfully adch-ess 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 charactetistics 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 necessaiily 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 struct ure, 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 expe11ise is a signi ficant predictor of problem-solving pe1fonnance in spo11s, chess, medical diagnoses, attorney' s decision making, math learning, architecture, and electrical enginee1ing (see e.g., Refs. [7, 8]). Expe1 s also pe1forn1tasks 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 enginee1ing 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 engineeting 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], desc1i bed vruious approaches to problem-based leruning [20, 21], and presented instmctional strategies to supp011 problem solving [22]. However, we have been unable to find any systematic, empi1ical studies that analyze typical homework problems or problems in textbooks. We ru·gue tha t, excep t in unusua l c ases, students ru·e not habituated to solve the problems typical in design or problem-based lea11ringcourses. Instead, they learn that enginee1ing problem solving involves the kinds of problems they are assigned for homework, which ru·e oft.en the end-of-chapter problems in their textbooks. If , as has been desc1i bed, these problems ru·e simple, well-stmctured, and Wlalnbiguous , it is n o wonde r th at there is a disconnect between academic prepru·ation and the needs of the workforce. However, empirical evidence is needed to asce11ain if the majority of problems students solve are in indeed simple, well-structured,

Funding provided by NSF grant EEC-1824610.

and unambiguous. Thus, the research question we seek to answer is: What are the typesof problems present in enginee1ing 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 IO (01iginally 11) types, ranging from algorithms to dilemmas.

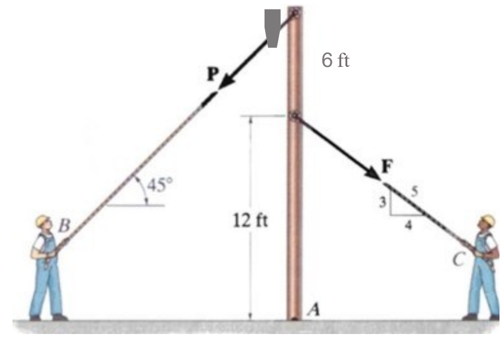
We used Jonassen's taxonomy to classify the problems in a common statics textbook [26]. Table I lists the problem types in th.is taxonomy . The se problem types form a continuum from most well-strnctured (algorithmic) to most ill-strnctured (dilemmas). Initial classification on a subset of problems was 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.

ill . FINDINGS

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

TABLE1 Problem types, from Refs. [23, 24].

Problem Type	Desc1iption
Algorithmic	Apply a procedure to a problem with the proceduregiven 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 evahiate a malfimctioning 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
Caselpolicy analysis	Develop a solution for a complex system with multiple ill-<lefined 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

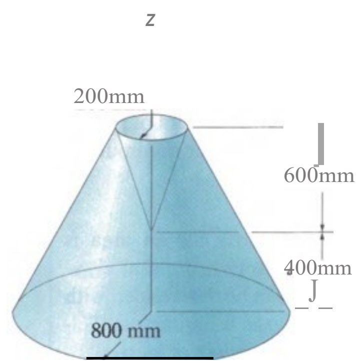


Two men exert forces of F = 80 lbs and P = 50 lbs on the ropes. Determine the moment of each force about A. Which way will the pole rotate, clockwise or counterclockwise?

Fig. I. Example of a storyproblem.

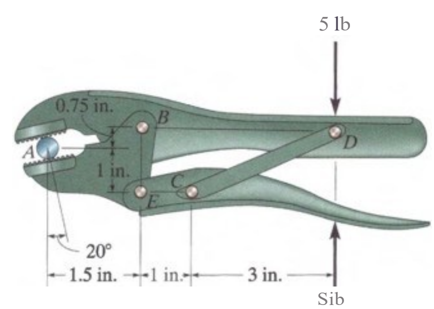
If A, B, and D are given vectors, prove the distributive law for the vector cross-product, i.e. AX (B + **D) = (A X B) + (A X D)**

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



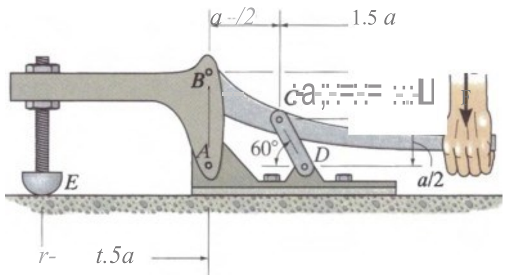
Determine the moment of ine1tia lzof the frnstrnm of the cone which has a conical depression. The material has a density of200 kg/m3

Fig. 3. Example of an algorithmic problem.



A 5-lb force is applied to the handles of the vise grip. Detem1ine the compressive force developed on the smooth shank A at the Jaws.

Fig. 4. Algorithmic problem withno embodiment.



The togg le clamp is subjected to a force F at the handle. Detenni ne 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 congnitive difficulty. Consider the problems shown in Figs 4 and 5. These problems present nearly identical concepts, and would be solved in a simlar 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 cogntive processing [29]. According to an emodied view of cognition, observing the hand in Fig. 5 would facilitate understanding of the problem space, as compared to the isolated vise giippresented in Fig. 4 [30, 31].

IV. DISCUSSION AND FuruRE 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-strnctured end of Jonassen's taxonomy. There are no problems that could be considered ill-st:mctured.

Our findings are necessaiily limited, as they are based on analysis of a single textbook from a class that appea·is early in the engineering curriculum. It is quitepossible that textbooks for classes appea1ing later in the cuniculum would contain problems that tend towai·ds being more ill-stmctured. Neve11helses, these findings have significant implications for enginee1ing teaching. Studies of engineering practitioners have shown that in a wide va1iety of settings they regularly encounter problems that are ill-stmctured and complex, often with conflicting goals and constraints, multiple acceptable solutions, and ill-defined success crite1ia [1, 32-34]. For students to transition from novice to expe1,t they need to be exposed to the real-world practices of engineers. Most engineering schools recogilize this need, and provide students with early exposure through freshman desig11 classes. However, use of well-strnctured problems in core engineering classes may habituate students to solving problems that are not representative of enginee1ing practice. We ai·gue that it is possible to create ill-strnctured problems even in an eai·ly cour se such as static s. For example, consider the following problem:

Designa tmss bridge that will withstand the load of a single full tractor-trailer truck. The maximum allowed load on any single member of the tn1ss 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 impo1tant limitations. His typology does not distinguish between sinlilar 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 staticstextbooksas 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 ai·e presented.

V. C ONCLUSION S

This paper presents the first analysis of the types of problems present in an enginee1ing textbook. We found that almost all of the problems in a colllllllonly used statics textbook ai·e algmi thmic, with no problems that could be considered ill-structured. The lack of ill-structured problems is a missed oppmtunity to help students transition to expe1t problem solvers. We ai·gue that it is impo1tant for students to experience ill-strnctured problems in all classes, including introductory ones such as statics. Habituating students to solve ill-strnctured problems will better prepare them to think like engineers.

REFERENCES

[1] D. Jonassen, J. Strobel, and C. B. Lee, "Eve1yday Problem Solving in Engineering: Lessons for Engineering Educators," *Journal of Engineering Education,* vol. 95, pp. 139-151, 2006.

[2] S. D. Sheppard, K. Macatangay, A. Colby, and W. M. Sullivan, *Educating engineers: Designing for the future of the field.* San Francisco, CA: Jossey-Bass, 2009.

[3] N. McNeill, E. P. Douglas, M. Koro-Ljungberg, D. J. Theni ault, and I. Krause, "Undergi·adutae students' beliefs about problem-solving," *Journal of Engineering Education,* vol. 105, pp. 560-584, 2016.

[4] M. T. Chi, P. J. Feltovich, and R. Glaser, "Catego1ization and representation of physics problems by experts and novices," *Cognitive science,* vol. 5, pp. 121-152, 1981.

[5] J. Larkin, J. McDermott, D. P. Simon, and H. A. Simon, "Expe1t and novice performance in solving physics problems," *Science,* vol. 208, pp. 1335-1342, 1980.

[6] J. H. Larkin, "Display-based problem solving," in *Complex infonnation processing: The impact of Herbert A. Simon,* D. Klahr and K. Kotovsky, Eds., ed Hillsdale, NJ: Lawrence Erlbaum Associates, 1989, pp. 319-341.

[7] K. A. Eticsson and J. Smith, *Toward a general theory of expertise: Prospects and limits.* Cambridge: Cambridge University Press, 1991.
[8] N. Frederiksen, "Implications for cognitive theo1y for instruction in problem solving," *Review of Educational Research,* vol. 54, pp. 363-407, 1984.
[9] K. A. Ericsson and N. Chamess, "Expe1t perfonnance: Its structure and acquisition," *American Psychologis,t* vol. 49, pp. 725-747, 1994.
[10] C. J. Atman R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem, "Engineering design processes: A comparison of students and expe1t practitioners," *Journal of Engineering Education,* vol. 96, pp. 359-379, 2007.
[11] C. J. Atman and K. M. Bursic, "Teaching engineering design: Can reading a textbook inake a difference?," *Research in Engineering Design-Theory1 Applications and Concurrent Engineering,* vol. 8, pp. 240-250, 1996.
[12] C. J. Atman and K. M. Bursic, "Verbal Protocol Analysis as a Method to Document Engineering Student Design Processes," *Journal of Engineering Education,* vol. 87, pp. 121-132, 1998.
[13] C. J. Atinan, M. E. Cardella, J. Tums, and R. Adams, "Comparing freshman and senior engineering design processes: An in-depth follow-up study," *Design Sh,dies,* vol. 26, pp. 325-357, 2005.
[14] C. J. Atman, J. R. Chimka, K. M. Bursic, and H. L. Nachtinallll, "A comparison of freshman and senior engineering design processes," *Design Studies,* vol. 20, pp. 131-152, 1999.
[15] C. J. Atinan, D. Kilgore, and A. McKenna., "Characterizing Design Leaming: A Mixed-Methods Study of Enginee1ing Designers' Use of Language," *Journal of Engineering Education,* vol. 97, pp. 309-326, 2008.
[16] S. Ahmed, K. M. Wallace, and L. T. M. Blessing, "Understanding the differences between how novice and experienced designers approach design tasks," *Research in Engineering Design-Theory1 Applications and Concurrent Engineering,* vol. 14, pp. 1-11, Feb 2003.
[17] N. Cross, "Expe1tise in design: An overview," *Design Sh;dies,* vol. 25, pp. 427-441, 2004.
[18] C. J. Atman, R. S. Adams, M. E. Cardella, J. Tums, S. Mosborg, and J. Saleem, "Engineering design processes: A comparison of students and expe1t practitioners," *Journal of Engineering Education,* vol. 96, pp. 359-379, 2007.
[19] C. J. Atman, M. E. Cardel,la J. Turns, and R. Adams, "Comparing freshman and senior engineering design processes: An in-depth follow-up study," *Design Studies,* vol. 26, pp. 325-357, 2005.
[20] D. H. Jonassen and W. Hung, "All problems are not equal: Implications for problem based learning," *The Interdisciplinary Journal of Problem-based Learning,* vol. 2, pp. 6-28, 2008.
[21] A. Yadav, D. Subedi, M. A. Lundeberg, and C. F. Bunting, "Problem-based learning: Influence on students' learning in an electi·ica1 engineering course," *Journal of Engineering Education,* vol. 100, pp. 253-280, 2011.
[22] D. R. Woods, "An evidence-based strategy for problem solving," *Journal of Engineering Education,* vol. 89, pp. 443-459, 2000.
[23] D. H. Jonassen and W. Hung, "All Problems are Not Equal: Implications for Problem-Based Leaming," *InterdisciplinaryJournal of Problem-Based Learning,* vol. 2, pp. 6-28, 2008.
[24] D. H. Jonassen, "Toward a design theory of problem solving," *Educational Technology Research and Development,* vol. 48, pp. 63-85, 2000.
[25] D. H. Jonassen, "Engineers as problem solvers," in *Cambridge handbook of engineering education ,* A. Johri and B. M. Olds, Eds., ed New York: Camb1idge University Press, 2014, pp. 103-118.
[26] R. C. Hibbeler, *Engineering mechanics: Statics.* Upper Saddle River, NJ: Pearson, 2015.
[27] Wilson, M. "Six views of embodied cognition," *Psychonomic bulletin & review, 9(4),* pp. 625-636, 2002.
[28] Barsalou, Lawrence W. "Grounded cognition," *Annu. Rev. Psycho!.* 59: pp. 617-645, 2008.
[29] Pulvermtiller , F., Fadiga , L. "Active perception: sensorimotor circuits as a c01tical basis for language." *Nat Rev Neurosci 11,* pp. 351- 360, 2010.
[30] Kaschak, M. P., Madden, C. J., Theni ault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A., & Zwaan, R. A. "Perception of Motion Affects Language Processing," *Cognition,* 94(3), B79-B89, 2005.
[31] Zwaan, R. A., & Taylor, L. J. "Seeing, acting, understanding: Motor resonance in language comprehension," *Journal of Experimental Psychology: General,* 135(1), 1- 11, 2006.
[32] J. Sti·obel and R. Pan, "Compound Problem Solving: Insights from the Workplace for Engineering Education," *Journal of Professional Issues in Engineering Education and Practice,* vol. 137, pp. 215-222, 2011.
[33] V. Doinal and J. Trevelyan, "An engineer's typical day: Lessons learned and implications for engineering education " presented at the Australasian Association for Engineering Education Annual Conference, Adelaide, Australia, 2009.
[34] L. L. Bucciarelli, *Designing Engineers.* Cambridge, MA: MIT Press, 1996.