

Cultivating Problem Solving Skills via a New Problem Categorization Scheme

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Abstract. When one looks at STEM disciplines as a whole, the need for effective problem solving skills is a commonality. However, studies indicate that the bulk of students who graduate from problem-solving intensive programs display little increase in their problem solving abilities. Also, there is little evidence for transfer of general skills from one subject area to another. Furthermore, the types of problems typically encountered in introductory STEM courses do not often cultivate the skills students will need when solving “real-world” problems. Initial efforts to develop and implement an interdisciplinary problem categorization matrix as a tool for instructional design are described. The matrix, which is independent of content, shows promise as a means for promoting useful problem-solving discussion among faculty, designing problem-solving intensive courses, and instructing students in developing real-world problem solving skills.

Keywords: interdisciplinary problem solving, STEM, problem categorization, teaching problem solving

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INTRODUCTION

When one looks at the STEM (science, technology, engineering, and mathematics) disciplines as a whole, one aspect that pervades all subdisciplines is the need for effective problem solving skills. Indeed, one might argue that teaching college students to problem-solve may be more important than teaching them specific content knowledge, given that it is nearly impossible to predict what specific content today’s graduates will need to know even 10 years from now.[1-6] However, studies indicate that the bulk of students who graduate from problem-solving intensive programs display little increase in their problem-solving abilities, even after solving thousands of problems.[7] Further, there is little evidence for transfer of general skills from one subject area to another, from one course to another, or even between different topics in the same course.[8] It has been argued that in order for students to achieve cognitive growth, they must solve a variety of types of problems, according to some taxonomy, such as Bloom’s.[9,10] This paper describes some initial interdisciplinary efforts to improve student problem solving skills via a new method of problem categorization.

CONTEXT OF THE WORK

The Fundamentals of Engineering for Honors (FEH) program at Ohio State has included some coordination of topics in physics, engineering, and mathematics since 1997 in an effort to 1) help students have appropriate background for each course and 2) assist students in making connections between the different subject areas. One common element in all three disciplines is problem solving, but until recently there had not been much discussion of this prevalent aspect of STEM education in the coordination efforts. It was postulated that the interdisciplinary nature of the FEH program would make it a useful setting to successfully impact the issues referred to in the introduction..

Interviews of FEH team members from a variety of disciplines indicated that there are few commonalities in the way different instructors describe problems.[11] Without a common framework it is difficult for instructors to describe problems from their courses to each other. Further, given that novices have a difficult time seeing commonalities within one discipline area, let alone across disciplines, without a common framework it should not be surprising that little transfer occurs from one discipline to another. If instructors are assigning problems with common characteristics, it would be useful to know and make this connection explicit to the students. If students begin to see some relationships between problem

solving in different courses, they might become more adept at problem solving. Likewise, if the instructors help students see that certain strategies and skills tend to be successful in approaching certain types of problems, it might have an impact.

DEVELOPMENT OF THE PROBLEM CATEGORIZATION SCHEME

A large body of work details the differences between how novices and experts solve problems. Of particular relevance here is that novices tend to categorize problems according to their surface features where experts categorize problems based on the concepts needed to solve the problem. [12] However, experienced instructors also know that students run into difficulty when encountering problems that go beyond “plug ‘n chug,” and require them to apply real-world skills such as approximating, making assumptions, estimating, or doing additional research to solve the problem. Part of this may be due to lack of practice with these skills; part of this may be due to a lack of recognition of when to appropriately apply them.

Although experts categorize in a deeper way than novices, the categorization is largely dependent upon the content knowledge that the experts have. A person can be an expert in one field and a novice in another, and so, if he or she is asked to categorize problems in two very different fields, may apply different strategies to each. Therefore, teaching a categorization scheme based upon content might be expected to have weaknesses because: 1) the instructor’s content knowledge is broader and better organized than the students; [13] and, 2) any skills learned that are highly connected to the content would not be expected to be transferable. Therefore, non-content aspects of problem solving should be expected to be more transferable.

The categorization scheme that has been developed is a two-dimensional matrix, where one axis indicates the nature of the solution (no possible solution, exactly one correct solution, or multiple correct solutions) and the other describes the nature of the given information (insufficient information, exactly sufficient information, or excess information). This scheme is indeed content independent. Additionally, typical STEM employees will encounter problems that fit in most, if not all, of these boxes in their work.

As an example of how this matrix works, consider Figure 1. Each cell of the categorization matrix contains a list of skills that might be appropriate to employ when solving a problem of this nature, regardless of its content.

As an example of how problems that are similar both in terms of basic content area and presentation fit into different blocks of the matrix, consider Figure 2 (at the end of the paper), which shows a set of nine similar yet different statics problems, each in the appropriate cell.

The point of this is that problems which share a number of common characteristics can be quite different in the manner in which they are successfully approached. Most problems typically encountered in introductory courses will fit into one of these matrix cells, although some problems might be better thought of as “mixed states” (e.g., a problem with some excess information, but other needed information lacking). The point is *not* that any problem situation can be modified to fit in all the blocks. In fact, it appears that many standard textbook problems can be rather easily modified to fit in about six blocks, but do not readily lend themselves to the entire matrix.

		Nature of the Answer		
		None	One	Two or more
Nature of Provided Information	Insufficient	Analyze Approximate Assess/Evaluate Assume Estimate Model Research Verify	Analyze Approximate Assess/Evaluate Assume Estimate Model Research Verify	Analyze Approximate Assess/Evaluate Assume Estimate Model Optimize Research Verify
	Exactly Sufficient	Analyze Assess/Evaluate Model Verify	Analyze Assess/Evaluate Model Verify	Analyze Assess/Evaluate Model Optimize Verify
	Excess	Analyze Assess/Evaluate Discriminate Filter Model Sort Verify	Analyze Assess/Evaluate Discriminate Filter Model Sort Verify	Analyze Assess/Evaluate Discriminate Filter Model Optimize Sort Verify

FIGURE 1. General Problem Categorization Matrix with Associated Skills

A look at chapters of two traditional texts (one in physics, one in mechanical engineering) indicates that the vast majority of problems are in the center square of the matrix, having exactly enough information and one correct answer. Figure 3 summarizes these findings.

One might think that the emergence of more “reformed” or research-based textbooks might better address the need for a variety of problem types. Although these books often do a better job of addressing conceptual understanding, the problem

distribution in these books is not much different than their traditional counterparts, as shown in Figure 4.

		Answers		
		None	One	> One
Information	Insuff		HRW 1.5%	
	Exact	HRW <1% BJ 2%	HRW 97% BJ 89%	HRW <1% BJ 9%
	Excess			

HRW - Halliday, Resnick & Walker, Physics, 6th Ed
 Ch 2 - Kinematics, Ch 4 - Kinematics 2 & 3 D
 (All end of chapter problems)
 BJ - Beer & Johnson, Statics, 6th Edition
 Ch 3 - Rigid Bodies, Ch 6 - Truss Analysis
 (114 problems)

FIGURE 3. Problem Distribution in Traditional STEM Texts

		Answers		
		None	One	> One
Information	Insuff		K <1% H 2%	K <1%
	Exact		K 89% ST 86% H 86%	K 9% ST 13% H 22%
	Excess			

K - Knight, Physics, 1st Ed
 Ch 2 - Kinematics, Ch 4 - Motion in a plane
 (All end of chapter problems)
 ST - Sheppard & Tongue, Statics, 1st Ed
 Ch 6 - Rigid Bodies, Ch 9 - Truss Analysis
 (100 problems)
 H - Hughes-Hallet, Calculus, 1st Edition
 Ch 2 - The Derivative, Ch 5 - Using the Derivative

FIGURE 4. Problem Distribution in Reform STEM Texts

ONGOING WORK

This summer (2006), the project team is in the process of soliciting a variety of problems from faculty

to see if they fit into the matrix to determine if further modifications are needed. Also, a sample of STEM faculty are reviewing the categorization scheme to see if 1) they agree with the descriptions, 2) they can add more terms to the matrix, and 3) they can think of any problems that do not fit in the matrix. Further tweaking may be necessary. Eventually, all basic problems in the FEH sequence should be categorized according to this or a similar scheme.

At the same time, a variety of problems are being developed to fill in the sparsely occupied boxes of the matrix, particularly for engineering graphics and physics mechanics, since these are two of the FEH courses that will be taught in the fall.

The next step will be to engage the FEH faculty in discussions to determine as a staff a strategy for utilizing this categorization as an instructional tool. Included in this work will be syllabus development, lecture modification, and problem selection. At the same time, a third axis will be added to the matrix, further categorizing problems utilizing a taxonomy such as Bloom's. This third classification will again assist the instructors in developing an approach to improve problem solving instruction, both within individual courses and also program-wide. As strategies are developed, the research staff will design an assessment plan for their implementations.

CONCLUSIONS

The problem categorization matrix, while still in its early stages, shows promise as a useful tool in guiding faculty problem-solving discussions. Using the categorization scheme to do a preliminary analysis of introductory textbooks has revealed that their problems usually do not require application of the real-world problem solving skills that STEM majors need; this could be one reason for the poor development of such skills cited in the literature. Development of additional problems to better cultivate these skills and utilization of the new categorization scheme by an interdisciplinary group of faculty may have a more substantial impact. Further development and research will show whether or not this is the case.

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Given a 5 T load find the vertical reactions. Supports can carry 2 T Max

Given a 5 T load find the vertical reactions

Given a 3 T load and a 2 T point load determine 2 locations for the loads that yield equal vertical reactions

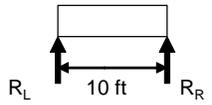
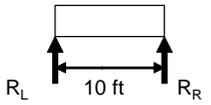
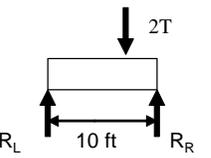
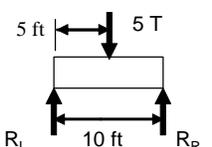
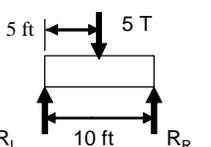
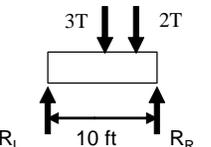
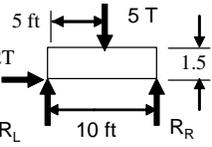
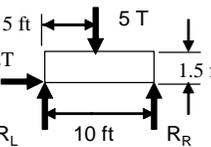
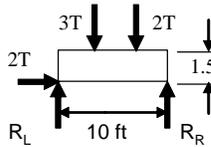
	No Answer	One Answer	More Than One Answer
Insufficient Information			
Exactly Enough Information			
Too Much Information			

FIGURE 2. Example Statics Problems in the Problem Categorization Matrix
Note that the problem statement at the top of each column pertains to each problem in that column.

REFERENCES

- [1] H. A. Simon, in *Problem Solving and Education: Issues in Teaching and Research*, edited by D. T. Tuma and F. Reif, Hillsdale, NJ: Lawrence Erlbaum Associates, 1980.
- [2] H. F. O'Neil, *Computers in Human Behavior* **15**, 255-268 (1999).
- [3] J. Schacter et al., *Computers in Human Behavior* **15**, 403-418 (1999).
- [4] A. P. Carneval et al., *Workplace Basics: The Essential Skills Employers Want* San Francisco, CA: Jossey-Bass, 1990.
- [5] D. Rosil, "What are Masters Doing?" College Park, MD: AIP Statistics Division, 1996.
- [6] See, for instance, the accreditation criteria of ABET.
- [7] D. Woods, *J. Coll. Sci. Teach* **23**, 157-158 (1994) and **12**, 446-448 (1983).
- [8] *How People Learn*, edited by J. Bransford et al., Washington, DC: National Academy Press, 1999.
- [9] R. M. Felder, and R. Brent, *Journal of Engineering Education* **93**, 269-277(2004).
- [10] R. M. Felder and R. Brent, *Journal of Engineering Education* **93**, 278-291 (2004).
- [11] J. Demel et al., in *Proceedings of the ASEE 2005 Annual Conference*, ASEE, 2005.
- [12] M. T. H. Chi et al *Cognitive Science* **5**, 121-152 (1981).
- [13] J. H. Larkin., *Engineering Education* **70**, 285-288 (1979).