2006-896: PROBLEM SOLVING IN ENGINEERING, MATHEMATICS, AND PHYSICS – PART 2

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Problem Solving in Engineering, Mathematics, and Physics – Part 2

Abstract

This is a work in progress dealing with problem solving across disciplines in an attempt to make engineering students better problem solvers. The purpose is to enable students to identify common types of problems in a variety of subject areas and to help them learn appropriate strategies suggested by each problem type. A previous investigation reported on a survey of math, physics and engineering faculty with respect to the types of problems they employed in their instruction.[1] A major result of this study was that little common vocabulary is used to describe problems and problem solving. Therefore, the additional result that the disciplines do not share a common approach to categorizing problem types and appropriate solution techniques is not surprising. In order for interdisciplinary efforts to make further progress, it appeared that a common language and framework were needed. The current investigation deals with developing a problem-solving vocabulary and then a method of problem categorization that could be agreed upon by STEM disciplines. Starting with problem-solving words that appeared in transcripts of the faculty interviews, a vocabulary list was developed by consulting dictionaries, faculty, and national problem solving experts. With this in hand, a matrix was developed to categorize problems. This framework shows some promise as a means for promoting useful problem-solving conversations among faculty, and may have explicit applications in the classroom, as well. Work in the immediate future will focus on sharing, testing, and improving the matrix. From there, it will be employed as a tool for curriculum design. Ultimately, studies will investigate if students in courses affected by this categorization scheme are more efficient and effective problem solvers, and if they more readily transfer problem-solving skills from one course to another.

Background

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 element that is particularly common 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. Some of the literature indicates that typical college experiences do not lead to much improvement in student problem solving skills[2-4] and that the problem solving skills that may develop in one discipline are not readily transferred to another content domain.[5] It was postulated that the FEH program with its interdisciplinary nature might serve as a useful setting for a successful attempt to impact these issues.

In initial conversations during FEH meetings, it was observed that the physicists had names for some of the sorts of problems they assigned, but it did not appear that the engineers or mathematicians did. Did this mean that different disciplines were assigning different kinds of problems or just that the physicists had developed terminology of which the other disciplines were unaware? If the instructional team was assigning common types of problems, it would be a useful thing for the members of the team to know. Further, given that novices have a difficult time seeing commonalities within one discipline area, let alone across disciplines, it would be good to make any problem solving links between courses clear to the students.

The thought was that if common problem types could be identified across the disciplines and described in a way that the instructors basically agreed upon, and that if the instructors referred to these common types of problems in their courses, that students might begin to see some connections between their courses. Further, if the instructors would help students see that certain strategies tend to be successful in approaching certain types of problems, the students might become more adept at interdisciplinary problem solving. If the students could match cues about the nature of a problem or the nature of its solution with a set of often useful skills, their approaches should be more effective than the random trial-and-error approach so often seen.

With these goals in mind, a number of faculty from each of the three disciplines were interviewed about the kinds of problems they utilized in their teaching; all were involved in teaching first-year engineering students. The results of these interviews were reported previously.[1] Two of them have a particular bearing on the work described here:

1) Some faculty cannot clearly articulate the types of problems they assign to their students, apart from detailing the content and/or context of the problem itself.
2) There were very few commonalities in the language the faculty used to describe the problem types they used.

It became clear that before meaningful conversations could occur between the faculty, a common vocabulary would need to be developed and agreed upon. This vocabulary would be increasingly valuable when instructors would talk to students about common problem types across the disciplines, as well as about useful strategies for approaching them.

Development of the Vocabulary and Matrix

The transcripts of the interviews from the previous phase of the study were carefully analyzed to identify terms faculty used to describe problems and problem solving skills. The research team added further terms that came up in their discussions of the interviews. Next the team drafted definitions for these terms as they specifically applied to problem solving, utilizing the interview transcripts, the relevant literature, and several dictionaries.[6]

After several iterations, the draft of the vocabulary was shared with the interview subjects for their feedback. This was an important step, because it verified that the definitions that had been developed were in accordance with the way the terms had originally been used by the faculty. Additionally, feedback was solicited from problem solving experts throughout the country. Moderate modifications were made based upon this input. The resulting list of forty-two terms is shown in Appendix A. A caveat given by one of the experts that is important to keep in mind is that it is unlikely that all people will agree on every aspect of every one of these terms.

However, this list appears to be fairly acceptable to those who have been consulted, both problem solving experts and STEM faculty.

As an example of how this process worked, consider Figure 1, which shows the evolution of the definition for "qualitative."

Iterations	Sources Involved
adj 1: involving distinctions based on qualities; "qualitative change"; "qualitative data"; 2: relating to or involving comparisons based on qualities; 3: not mathematical or numeric, not expressible as a quantity	Dictionaries
Relating to or involving comparisons based on qualities but not mathematical or numeric; a feature or characteristic not expressible as a quantity; not mathematical or numeric, not expressible as a quantity	Research Team
Relating to or involving comparisons that are non-numeric	Research Team
Relating to or involving characteristics, relations, or concepts that are non-numeric	OSU Faculty, National Experts

Figure 1, The Evolution of "Qualitative"

Now that a common vocabulary was developed, the next step was to utilize this language to categorize and describe different types of problems. There are certainly a number of different ways this might be attempted. The team decided to begin with 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).

As an example of how this matrix works, consider Figure 2. Each cell contains a list of skills that might be appropriate to employ when solving a problem of this nature.

Nature of Provided Information		Nature of the Answer: None	Nature of the Answer: One	Nature of the Answer: Two or more
	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 2, General Problem Categorization Matrix with Associated Skills

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 3, which shows a set of 9 similar yet different statics problems, each in the appropriate block.

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. At this time, it appears that most problems typically encountered in introductory courses will fit into one of these matrix blocks. The point is *not* that any problem situation can be modified to fit in a different block of the matrix. In fact, the team came up with several problem situations that were not easily modifiable to fit all the blocks of the matrix, but that would fit in 6 blocks rather easily.

Recall that the purpose of this matrix, as well as the vocabulary list, is to facilitate discussions among interdisciplinary faculty concerning problem solving. In current plans, it is highly unlikely that students will see the exact matrices presented here, but they may see some modification. The goal is not to encourage a cut-and-paste approach to problem solving, but to aid students in identifying key features of problem situations that lend themselves well to particular approaches. Given that the tendency of novices to categorize problems based on their surface features is well established in the literature,[7] giving students a new categorization scheme may help them be more successful.

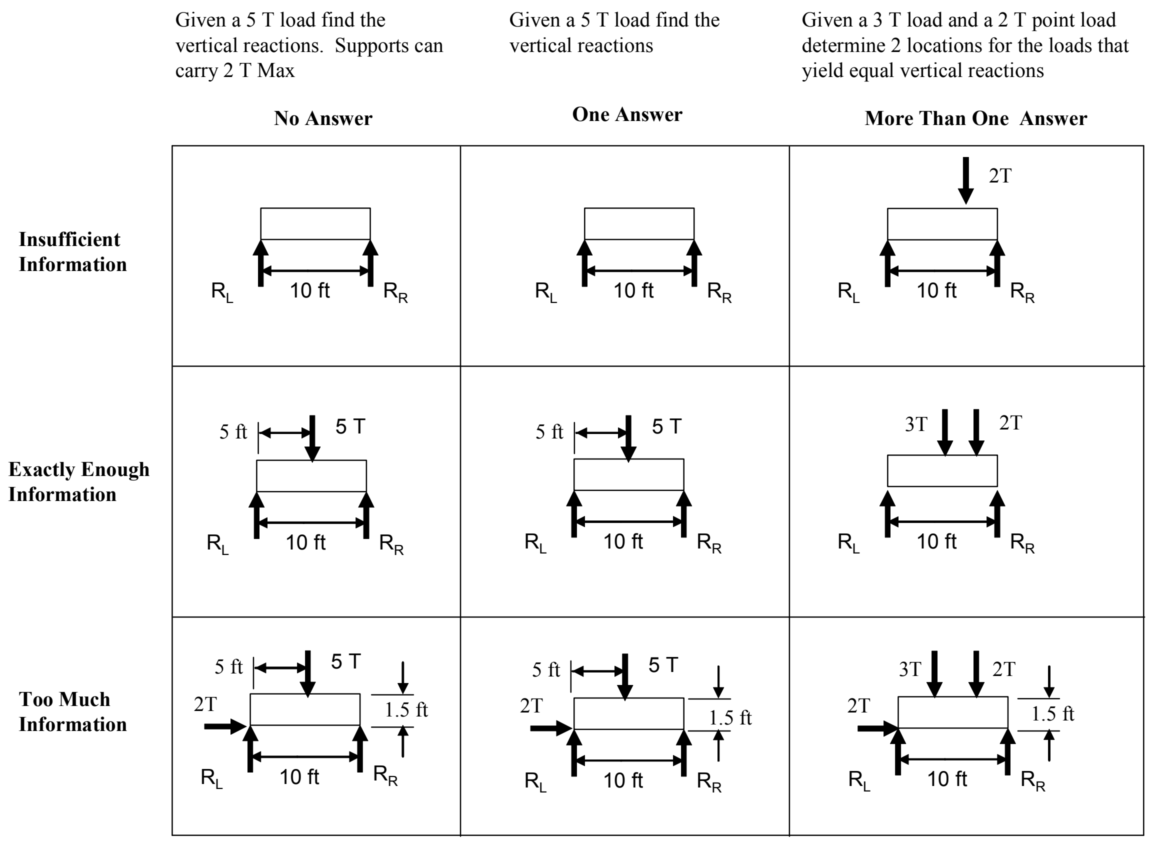

Figure 3, Example Statics Problems in the Problem Categorization Matrix
Note that the problem statement at the top of each column pertains to each problem in that column.

Future Work

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 it needs further modification. Also, the original sample of STEM faculty are reviewing the matrix 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. One area of current debate is whether authentic design problems fit in the current scheme, or whether an additional set of categories is needed for them.

The next step will be to engage the FEH faculty in discussions over the summer 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 Bloom's or another taxonomy. 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. It is anticipated that that a portion of this assessment will be done using matched pilot and control groups.

Conclusions

The vast majority of the problem-solving vocabulary list that was developed is acceptable to the STEM faculty and problem-solving experts who were consulted. Of course, not every definition is written with the precise wording that every individual thinks is optimal, but most definitions are acceptable to most of the people. The problem categorization matrix, while still in its early stages, shows signs of being a useful tool in guiding faculty problem-solving discussions. It should prove particularly useful with instructors (such as some from the first study) who have difficulty describing a problem apart from its subject matter or surface features.

Overall, the STEM faculty who have been involved in this project tend to agree that there is a need to approach problem solving in a more interdisciplinary way and (particularly when presented with the results from the first study) realize that a foundation is needed in order to do so. When reviewing the proposed vocabulary, some gave simple 'yes' or 'no' answers while others compared terms and challenged the definitions. The next phase of this work - introducing the vocabulary and problem types – will require cooperation from the faculty as they set up their courses, write the syllabi, and prepare their presentations. For this project to be successful in reaching the students, all of the FEH faculty must be involved.

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Appendix A: Problem Solving Vocabulary List

Analyze - to examine methodically by separating into parts, identifying the essential features of each, and studying the relationships among them.

Answer - the goal or final step of a solution process

Approximate - to choose a seemingly reasonable value, quantity, or function when a needed value, quantity, or function is not given or known.

Assessment - the process of determining the appropriateness of a solution step or correctness of some portion of the problem solution

Assume - to attempt to remove complexity from a problem situation in order to make the problem solvable or easier to solve. Not all assumptions may be explicit.

Belief - strong mental acceptance, perhaps unfounded, of the truth, actuality, or validity of something

Cognition - the mental processes of knowing, including aspects such as awareness, perception, reasoning, and judgment.

Complex - consisting of interconnected or interwoven parts

Concept - a general idea used to identify a system and explain relations among its components.

Construct - (v.) to form by arranging, combining, or assembling parts
- (n.) a concept, model, or schematic idea

Context - the circumstances and surroundings in which an event occurs or is described to have occurred

Contrived - fabricated, invented, or obviously planned; may or may not be realistic.

Convictions - strongly fixed beliefs, which may or may not be true

Defined - having the essential qualities or meanings specified or determined

Design - (v.) to systematically create an object, process, or system for a particular role or purpose
- (n.) the somewhat detailed plan for an object, process, or system desired for a particular role or purpose

Diagram - a plan, chart, graph, sketch, drawing, or outline designed to demonstrate or explain how something works or to clarify the relationship between the parts of a whole.

Dilemma - a state of perplexity, especially as requiring a choice among equally favorable or unfavorable options

Estimate - (n.) A tentative evaluation or assumption of worth, quantity, or size
- (v.) To tentatively evaluate or assume something's worth, quantity, or size

Evaluate 1. to examine and judge carefully in order to determine the plausibility of a or a portion of a solution.
2. in a mathematical context, to insert numbers into an algebraic expression and calculate the resulting number.

Exercise - a situation to be considered or question to be answered to which a solution path is obvious.

Filter - to sort through presented or obtained information or potentially useful ideas to determine the usefulness of each piece

Generate - to produce potentially useful ideas.

Integrate - to bring initially disparate parts together to form a more unified whole

Inquiry - a systematic investigation of a situation to obtain information (or truth?)

Judgement - the formation of an opinion by distinguishing, considering, and/or deliberating, based upon seemingly relevant experience.

Meta-analysis - experts: The process of synthesizing results and/or looking for broader patterns by using various methods to retrieve, select, and combine results from previous separate but related experiences.
- novices: The process of learning general skills by using various methods to retrieve, select, and combine results from previous experiences.

Metacognition - awareness and perhaps understanding of one's thinking and cognitive processes; thinking about thinking

Model - (n.) a description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used either for further study of its characteristics or for predictions about its future behavior
- (v.) to describe a system, theory, or phenomenon in order to account for its known or inferred properties and to use either for further study of its characteristics or for predictions about its future behavior

Opinion - a point of view, possibly held with confidence, but not necessarily substantiated by proof or certainty

Optimize - to make as effective or as efficient as possible, usually within given constraints.

Principle - a basic law or rule

Problem - a situation to be considered or question to be answered to which a path to a solution is not obvious.

Qualitative - relating to or involving characteristics, relations, or concepts that are non-numeric

Quantitative - relating to or susceptible of numeric measurement

Real World - practical, commonly experienced, or non-idealized

Representation - an instantiation of information, such as a graph, picture, mental image, or verbal description

Research - scholarly or scientific investigation or inquiry.

Self-efficacy - an individual's estimate of his or her own ability to succeed in achieving a specific goal or performing a particular task.

Solution -
1. the method or process of finding an answer to a problem
2. an artifact depicting the method or process of finding an answer to a problem

Solve - to produce a correct answer to a problem, along with the correct process for obtaining it.

Unsolvable - referring to a problem for which no answer is obtainable/findable

Verify - to determine the accuracy or correctness of, as by comparison, investigation, or reference