Helping Students Make the Transition from Novice to Expert Problem-Solvers

Michael Prince¹ and Brian Hoyt²

Abstract — Engineers, by definition, need to be good problem solvers. This paper discusses a model for building on a traditional engineering curriculum to systematically develop students' problem solving skills. The curriculum structure consists of required courses that emphasize problem solving at distinct levels. The courses are broken down into introductory, intermediate and advanced problem solving courses. The type of problems utilized in each course differentiates the courses. The problems posed are qualitatively different, not simply harder, thus requiring the students to engage different skill sets for resolution. As a result, the courses develop different problem solving abilities.

The model for teaching problem solving has been developed through Project Catalyst, which is an NSF funded initiative to improve undergraduate engineering education. This paper presents the details of the proposed model, discusses educational modules that have been developed to aid instructors introducing problem solving in their courses and provides some initial assessment of the results to date.

Index Terms — Curriculum Design, Problem Based Learning, Teaching Problem Solving.

INTRODUCTION

Engineers, by definition, need to be good problem solvers. In fact, the Accreditation Board for Engineering and Technology (ABET) now requires that all engineering programs demonstrate that students have the ability to "identify, formulate and solve engineering problems". Few engineering faculty would disagree with the importance of this criterion. However, the traditional undergraduate engineering curriculum is not designed to systematically develop relevant problem solving skills. Consider, for example, that the bulk of the curriculum emphasizes facts, formulas and low level textbook exercises. In fact, an analysis of one four-year engineering program found that approximately 80% of problems assigned to students required only low-level thinking skills [8]. The authors classified problems using Bloom's taxonomy, and concluded that most problems did not require any analysis, synthesis or evaluation. In addition, a traditional engineering program reserves most of the higher level thinking, such as design, until the senior year. And finally, a traditional program relies on constant repetition of textbook problems to develop problem solving skills but would typically not include any formal training in problem solving methodologies.

What is the problem with this approach? Most of us have gone through programs like this and may have taught this way for years. However, there is reason to think that we can do better. At Bucknell University, a group of engineering faculty involved in a NSF funded initiative to re-envision engineering education [3] has developed a different model to teach problem solving based on several arguments, described below:

How We Learn Skills

We all acquire skills in one way and one way only, through practice and feedback. Students learn how to identify, formulate and solve engineering problems by identifying, formulating and solving engineering problems and then getting feedback to learn from their experience. In a proper educational environment, guidance as well as feedback would be provided.

How does this relate to a traditional engineering program with the heavy emphasis on textbook exercises? It is clear that one of the critical flaws of relying heavily on textbook problems is that they do not generally require relevant problem solving skills. The textbook authors have already identified and formulated the problem, which is now an exercise that typically requires only application of material from that chapter to solve. That is not "problem solving", in any real sense and would not satisfy the accreditation criterion on problem solving or prepare students for industrial practice.

The Importance of Context

Even recognizing the limitations of traditional textbook problems, some may argue that textbook problems build the foundation for more relevant things. There's probably some truth in that. However, textbook problems are artificial and generally lack a relevant context, or at least one that is genuinely relevant to the student. For that reason alone, textbook exercises aren't ideal teaching tools. Perhaps more importantly, there is evidence to suggest that students who only solve textbook problems are not likely to be able to apply the concepts to real problems [2]. In response to some of these concerns, some of the authors have adopted the use of problem-based learning in their courses and have structured the classes so that relevant and realistic problems drive most of the learning that occurs [7].

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Principles of Good Instructional Design

One of the principles of good instructional design is to develop student skills and responsibilities in a gradual way so that students make the transition from novice to expert problem solver easily over time. Students should be introduced to relevant problem solving early in the curriculum and gradually encouraged and trained to adopt appropriate problem solving skills. This assumption about instructional design underlies the tiered curriculum structure described in this article and elsewhere [4].

Developing Problem Solving Skills: A Staged Curriculum Model

Based on these ideas, the authors have developed a tiered curriculum model to develop problem solving skills throughout the engineering curriculum and have begun to implement the model at Bucknell University. The curricular structure to promote problem-solving skills consists of core courses phased throughout the curriculum that emphasize problem solving at distinct levels. The courses are broken down into introduction problem solving courses (P1), intermediate problem solving courses (P2) and advanced problem solving courses (P3). The type of problems utilized in each course differentiates the courses. The problems posed are qualitatively different, not simply more difficult, thus requiring the students to engage different skill sets for resolution. As a result of the distinct problem types used, the courses develop different problem solving abilities. Since these courses are staged throughout the 4-year curriculum, students gradually receive practice and instruction in a broad range of problem solving skills. As a result, students are gradually weaned away from textbook problems and develop more practical problem solving abilities.

Table 1 provides a definition and example of the type of problem encountered at each level of problem solving in the curriculum. The table also identifies where courses tend to fall in the four-year curriculum and maps learning outcomes associated with each course to Bloom’s taxonomy. One can see that there is a steady progression in the range of problem solving skills required and in the level of Bloom’s taxonomy as students move through the levels of problem-solving in the undergraduate curriculum.

While there is not a complete separation of problem type used by course designation, a designated course will emphasize problems of a certain level. Therefore, while an intermediate problem-solving course may contain some P1 and P3 type problems, the major emphasis will be on vaguely defined problems requiring significant problem definition on the part of the student. A more detailed description of each level of problem solving is described below.

Introductory Problem Solving Courses

Introductory problem solving or P1 courses emphasize well-defined problems having unique solutions and often unique solution methodologies. These are the types of exercises that are frequently found at the end of textbook chapters. Many of these problems rely on “problem recognition” and applying known algorithms. In introductory problem solving courses, students must develop the knowledge base to recognize the problem, choose an appropriate algorithm and execute it. For example, students in a course on heat transfer might be asked to calculate the heat flux through a wall, given the wall materials, thickness and temperatures of each surface.

This type of problem solving happens in many classes. While routine, it develops skills that are prerequisites for more advanced problems. In addition to providing the technical knowledge base necessary for engineering practice, introductory problem solving courses can be used to develop a number of general problem-solving skills. Specific learning outcomes associated with introductory problem solving courses include the ability to:

- recognize routine engineering problems and choose appropriate solution algorithms.
- map out a solution plan.
- obtain relevant information necessary to solve the problem.
- make and evaluate appropriate assumptions.
- draw appropriate conclusions.

Some of these skills, especially the ability to recognize a problem and plan a solution strategy, are elements of several published problem-solving methodologies. Therefore, instructors might think about introducing students to a formal problem solving methodology in introductory or subsequent courses emphasizing problem solving. We have introduced students to the well-known methodology of Donald Woods [6] because of its wide recognition and acceptance in engineering education. The specific methodology adopted is not central to the curriculum structure proposed in this article, though Woods makes an articulate argument for his approach and provides a good overview of the literature for interested readers.

Intermediate Problem Solving Courses

Intermediate problem solving or P2 courses utilize problems that are more realistic in that they are vaguely defined. The significant difference from P1 courses is that intermediate problem solving courses emphasize problem definition in a way that is not present in introductory problem solving courses. This is accomplished by phrasing the problem in such a way that there is some ambiguity and uncertainty. A common approach used in these courses is to embed the problem in a scenario that one might encounter if one were a
consultant and just hired by an organization to correct a problem.

Using the example in Table 1, students in a heat transfer course might be asked to assume the role of an engineering consultant brought in to analyze why the heating system does not maintain a comfortable room temperature. A common reason might be that the system is not adequately sized to handle the heat loss from the room, which students can determine by examining the specifications of the heating system and the relevant room characteristics. Students, however, must examine the problem and do the required analyses to determine the problem. Only then can they make a rational recommendation to address the problem.

The use of ill-defined problems develops critical problem solving skills that our students need. However, this is not necessarily design, nor does it require a great deal of creativity or synthesis. While having upped the ante, so to speak, by requiring significant and practical problem solving skills, the problems differ from those found in traditional design courses in that no significant amount of real design is necessary. However, there is a critical difference from P1 courses in that students must put the problem into a solvable form. Only then can students apply appropriate algorithms to complete any necessary calculations to solve the problem.

As with introductory problem solving courses, there are specific learning outcomes associated with intermediate problem solving courses that are independent of technical content. The generic learning outcomes associated with intermediate problem solving courses are:

- Those from P1 courses, which are foundational.
- The ability to define a problem.
- The ability to assess that the solution developed adequately addresses the given problem.

### ADVANCED PROBLEM SOLVING COURSES

Advanced problem solving or P3 courses emphasize problems that require significant elements of creativity. These might be the types of problems found in senior design courses. Here, design is described as ill-defined problems (poorly defined problem statements, goals or both) with multiple solutions and solution methodologies possible. In essence, the magnitude of the ambiguity changes from intermediate courses. The problems become one of scale and scope. The students are asked to start at the beginning and to build something rather than fix something. If the instructor is embedding the problem in the context of a consulting problem, the student as consultant might be asked to design a plant of some sort—which would be different from the type of ill-defined problem encountered in an intermediate problem-solving course. Advanced problems allow for more creativity and for more errors.

The specific learning outcomes associated with advanced problem solving courses include:

- All of the skills developed in P1 and P2 courses.
- Ability to generate creative solutions to address the real problem.
- Ability to evaluate and choose among multiple possible solutions.

### ASSESSMENT OF PROBLEM SOLVING

Assessment of results of the curriculum structure to develop problem-solving skills is preliminary at this point. We are still in the process of developing appropriate modules and instructor materials to develop problem-solving skills. We are also still in the process of fully integrating the staged approach for problem solving into the curriculum. However, we have systematically surveyed both faculty and students involved in Project Catalyst on the effectiveness of the courses for developing problem-solving skills. Because the Chemical Engineering program has achieved the highest level of curriculum integration at this point, the survey results are shown from chemical engineering courses in the sophomore, junior and senior years. Those results are shown in Table 2. While survey data are only one measure of the effectiveness in achieving, learning outcomes, there is some evidence to suggest that survey data correlate reasonably well with other objective measures. For example, Pike [4] found that self-reported measures of educational gains were as valid as objective measures. For instance, Table 2.

#### TABLE 1. STAGED LEVELS OF PROBLEM SOLVING

<table>
<thead>
<tr>
<th>Course Level</th>
<th>Definition</th>
<th>Example</th>
<th>Bloom's Taxonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P1: Introductory Problem Solving</strong></td>
<td>Recognition and application of routine algorithms</td>
<td>Calculate the heat flux through a wall of known composition</td>
<td>Knowledge, Comprehension, and Application</td>
</tr>
<tr>
<td><strong>P2: Intermediate Problem Solving</strong></td>
<td>Solution of poorly-defined problems requiring students to reformulate problem into a solvable form before applying algorithms.</td>
<td>Determine why a room's heating system does not maintain a comfortable temperature</td>
<td>Analysis</td>
</tr>
<tr>
<td><strong>P3: Advanced Problem Solving</strong></td>
<td>Solution of open-ended, vaguely-defined problems requiring significant creativity. Comparing alternative design solutions.</td>
<td>Design a new heating system for a room that meets size and cost constraints.</td>
<td>Synthesis and Evaluation</td>
</tr>
</tbody>
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3
The results show a high degree of consistency between students and faculty and from course to course. Both students and faculty moderately to strongly agree that the targeted courses were effective for developing a range of problem solving skills. In addition, both students and faculty moderately to strongly agree that the targeted courses were more effective for developing problem solving courses than traditional courses.

**CONCLUSIONS**

The Project Catalyst team has developed a conceptual framework for progressively developing students' problem solving skills across the curriculum. The framework consists of three distinct levels of learning outcomes. Work has begun on developing generic curriculum modules that are not course or discipline specific which faculty can use to promote student attainment of the outcomes specified in each framework. Preliminary assessment efforts indicate that both faculty and students perceive that the course sequences in which the problem solving framework was implemented improved students' problem solving skills and that courses were more effective than traditional courses in developing these skills.

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**REFERENCES**


Session


