Many students struggle to succeed in introductory technical courses at the undergraduate level. Often, students enter courses with poor or folklore-inspired physical understanding of the world around them. Additionally, many struggle with the mathematical skills needed to conduct analysis in science, technology, math and engineering courses. Weakness in math only serves to exacerbate the situation—in part because it builds in an extra source of error for students and because students do not necessarily see the connection between math and physical reasoning. As a result, students struggle with problem solving in technical courses in that they lack conceptual understanding of physical systems and have trouble modeling physical systems for the purpose of analysis. In short, they may not pick the right equations to use and, likely, will not apply appropriate assumptions to those equations as a means of simplifying them.

Typically, novices in technical areas tend to attempt problem solving in a much different manner than experts. In this case, the experts are faculty in research or education-focused undergraduate and graduate level programs. While the experts often start by analyzing a given physical system in conceptual terms prior moving to actual modeling and mathematical operations, ultimately solving systems of equations and solving for a final answer, novice students do not. Often, students begin by solving a problem by picking mathematical equations, substituting given variables and then hunting for new equations that seem to fit (Caliskan, 2009). Typically, these students are either hunting for equations that have what seem like the right variables or they are mimicking problems seen in lecture periods and their texts. This process is generally not informed by physical reasoning.

In the last two decades, a number of studies have been conducted on improving student problem solving skills. These studies often make the process of modeling a system a course-level objective (Halloun, 1996) and they also focus on teaching students expert-level problem solving techniques (Heller, 1992). All of these studies of pedagogical technique sought to make students active participants in the learning as much as they worked to impart generalized problem solving skills to students and teach discipline-specific information and application.

Current Practices

One of the most common practices in teaching physics and engineering courses is problem-based learning, which has its origins in the late 1970s (Sahin, 2006). This is a widely accepted practice in
disciplines that require application of knowledge as opposed to rote learning (Darmofal, 2001). It is an appealing technique because problems focus discipline-specific learning and the act of solving problems serves to improve general problem solving skills. Additionally, it provides relevance (and incentive to continue) to students by grounding coursework in real-world issues, systems, and problems. As mentioned above, math skills, physical reasoning, and problem solving methods are all inherent to success in technical courses and deficiencies in these areas significantly hamper students. Some researchers have made a concerted effort towards developing methods to improving physical reasoning and problem solving skills as a part of teaching within a specific discipline. This has the benefit of improving comprehension within that discipline and developing skills that can be generalized and used within other fields.

**Techniques for Improving Problem-Based Learning**

There are several methods that researchers have designed and implemented in trial studies in order to improve student comprehension of technical material. In large part, these initiatives have come from the physics community in both the US and Turkey at the high school, undergraduate and graduate levels of education (Heller, 1992) (Caliskan, 2009). There are two main thrusts within this effort. First, researchers worked to improve the teaching of modeling systems for analysis and application of a consistent problem solving methodology. Secondly, researchers have explored the impact of structured group problem solving during labs and recitation sections (groups of 3 students) while using improved, context-rich, problems.

**Implementation**

Heller describes a 3-phase approach to developing improved problem sets in physics education. The goal of this effort was to develop context-rich problems that encourage students to adopt improved problem solving strategies. This project sought to produce problems that moved student discussion away from figuring out what formula to use and towards determining, from the outset of problem solving, what physics concepts are most applicable to the given problem (Heller, 1992).

Additionally, Heller describes general characteristics of context-rich problems. The problems follow a short-story type format and are rooted in real-world situations (albeit humorous in some cases) that provide a rational for conducting analysis. Context-rich problems do not always state the unknown variable that must be solved for. This characteristic helps to defuse the novice effort to immediate find an equation with a given variable in it and it requires students to decide which principles and concepts will help them isolate a variable that will answer the question. These problems will typically have extraneous information that requires students to make judgment calls about relevance and they may lack key information and thus require students to make appropriate assumptions to aid their analysis. All of these characteristics of context-rich problems utterly stupefy the novice problem solving method (there’s no place to start) and absolutely require students to engage in a more mature problem solving method.
Problem-based learning, that involves real-world scenarios which are more open-ended and rich in context (to borrow a phrase), requires more effort to solve than problems seen in traditional math, physics, and engineering texts. To that end, group problem solving comes into play and offers the opportunity to improve problem solving efficiency and efficacy. Within well-functioning and structured problem-solving groups there lies the capability for the group to surpass the performance of a single group member (Heller, 1992). The group problem-solving format also provides students with sounding boards for developing, testing, and either rejecting or approving a hypothesis. That process is definitely characteristic of mature or expert problem solving. For the most part, groups of three were used in these studies and it proved to be advantageous to mix levels of competency (high, medium, and lower performing students in the same group), mix gender, and assign rotating roles within the groups (manager, skeptic, checker/recorder) (Heller, 1992).

Overall, there is a significant effort required in order to restructure courses to implement strategies for improved comprehension and improved general problem solving capability. The largest bill to pay comes from developing quality problem sets that stimulate mature problem solving. There is also an additional amount of work that goes into retraining instructors and graduate teaching assistants such that they promote mature problem solving methodology as a matter of course in their instructional method. In institutions that reward and promote faculty based on research and publishing, this requires faculty to put value in being an educator as well as a researcher or research manager (in the case of some faculty). The world of higher education does not often provide much reward for actually becoming a better educator or fostering better learning.

**Best Practices**

There are a number of techniques for improving conceptual understanding and application of analytical tools in technical courses. Among the strongest are:

1) Development of context-rich problems that, by their nature, require students to engage in expert-style problem solving methods and are rooted in relevant scenarios.

2) Explicitly teaching and demonstrating the desired problem solving methods in class.

3) Making use of structured and focused problem-solving groups. The groups foster dialogue and enable students to wrestle with concepts while also improving overall problem solving efficiency.

4) During instruction, focusing on the relation between math models and physical phenomena - thereby connecting the two domains and fighting the novice tendency to divorce math from physical processes.

5) Training faculty and graduate teaching assistants to facilitate student discussion and mature problem solving methods.

**Conclusion**

Students tend to struggle as they enter into undergraduate level science and engineering courses. This is largely due to either immature problem solving skills, weaknesses in pre-requisite math skills, and
misconceptions about physical phenomena. Faculty can effectively combat these problems by specifically training students to be expert problem solvers, fostering functional problem solving groups, and ensuring that the very problems that students solve encourage improved problem solving methodology.

Annotated Bibliography


This paper outlines an effort to design and test a rubric for assessing the quality of problem solving processes in students' written physics problem solutions. The overarching goal of this process was to bolster course-wide efforts to improve student problem solving along with teaching undergraduate-level physics.


The physics problem-solving performance of high school and college students is compared between a control group that received traditional instruction and an experimental group that participating in problem solving tutorials following the schematic modeling approach. The problem solving tutorials resulted in an appreciable improvement in the problem solving performance of the experimental group. In addition to describing the schematic modeling approach, the author points out that this method is generic in that is can be generalized to other technical fields outside of physics.


This paper outlines an effort at MIT to move from a traditional theoretical aerodynamics curriculum to a learner-centered curriculum emphasizing industry-inspired and design-based analysis involving group problem solving, analytical solutions, computational methods, experimental method and error estimation. It is important to note that this effort was bolstered by the involvement of the Lockheed Martin Corporation in providing MIT with real-world analytical scenarios.


The authors of this paper present a hypothesis about core instructor beliefs concerning how students best learn to solve problems and key aspects of metacognition required for successful problem solving in introductory physics courses. This effort is tied directly to later papers in which Heller and other seek to develop problem content and instructor methods that actively encourage appropriate problem-solving metacognitive processes.

Sahin presents an overview of factors that improve the efficiency of problem-based learning (PBL) along with highlighting the positive effects of PBL on student performance and attitudes. The author points out that PBL is enhanced by using small groups for problem solving, the integration of related disciplines to emphasize context and connection of concepts, and ensuring that instructors understand how to use PBL in the classroom.


This study compared the performance of a control group that received traditional physics instruction and that of an experimental group that received instruction on problem solving strategies as part of an introductory physics course. Students were randomly chosen to be in either group. The effect of the problem solving instruction was based on both pre and post course testing and it was shown that problem solving strategy instruction had a positive and tangible impact on the performance of students.


The authors outline a method for physics instruction involving the development of context rich problems, the incorporation of problem solving groups into labs and recitation sections, and teaching and explicit problem solving strategy as part of class. A technique was developed to evaluate the quality of problem solving performance and this method was shown to improve problem solving performance.


Heller extends her previous work by explaining methods that improve function in student problem solving groups. This paper gives a detailed account of how to achieve strong group performance through group size, gender and ability composition, seating, role assignment, text use and testing.

Additional References