# Helping Students Recognize and Solve Different Problem Types in Engineering, Mathematics, and Physics

**John T. Demel and Richard J. Freuler**
**First-Year Engineering Program**
**Kathleen A. Harper**
**Department of Physics**
**The Ohio State University**

**Abstract**
In the Fundamentals of Engineering for Honors (FEH) program (three parallel course sequences in mathematics, engineering, and physics) at Ohio State, the faculty members from these disciplines meet weekly and coordinate their teaching efforts so that topics are presented in a timely fashion. The purpose of this coordination is to help the students see the interconnections between the various disciplines and understand how physics and mathematics are used in engineering to solve problems. Mathematics is using the *Calculus* (Harvard Calculus) text by Deborah Hughes-Hallett, et al. (1) This text says that each topic should be presented "geometrically, numerically, and algebraically." The Physics Department is using *Physics for Scientists and Engineers*: *A Strategic Approach* by Randall D. Knight. (2) His stated approach to problem solving is to "model, visualize, solve and assess." Both of these books counsel not to do the algebra until problems are defined. However, most students in the FEH program come from high schools where the emphasis was on finding the correct formula and then plugging in the numbers. Currently the mathematics, engineering and physics faculty members do not share explicitly a common approach to categorizing problem types and how to solve them. This work in progress is focused on having these faculty members discuss problem solving, decide on a common approach, and present problem solving as an integrated topic in each of the three course sequences. This paper will describe the process of determining a consistent approach to problem solving, the planning necessary for implementation in 2005-06, and an assessment process to compare a pilot group to control group(s). The ultimate goal is to make the learning process more efficient for the students and to aid them in seeing more connections between their courses.

**Background**
In the FEH program since 1997, physics, engineering, and mathematics have been coordinating the topics so that students have the appropriate background for each of the courses. However, the three units have not collaborated on the types of problems that the students are solving in each of the classes. This project is focused on fostering more collaboration of this type so that students begin to recognize problem types across the disciplines.

Physics
The physics faculty members who work with the FEH program have been using a variety of active learning approaches in teaching mechanics and electricity and magnetism. Incorporated in this work have been active learning strategies that emphasize both

physics concepts and solving numerical problems. The approach has been to learn the concepts first and then apply them to physics problems. Some of the problem solving is done in small cooperative groups and some is done individually.

In addition to traditional end-of-chapter problems and exercises, the students work a variety of alternative problem types, most of which have been discussed in the physics education literature. (3) These alternative problem types have been developed to aid students in developing more expert-like problem solving skills, and as such typically require students to operate in the upper levels of Bloom's taxonomy. The problems typically found in most texts are classified lower on the taxonomy. Below is a list of some of the alternative problem types that have been used in FEH physics over the past few years, along with a short description of each. The range of Bloom's levels is given in parentheses.

1. Context Rich Problems: These were developed as a specific tool for use in cooperative group problem-solving sessions. The goal of these problems is to shift student discussions from a formulaic focus to one concerning the applicability of principles. Context rich problems, as the name implies, place the student in a more complex and real-world context than traditional problems. Students may have to determine what the target variable is, discard extraneous information, look for missing information, or make simplifying assumptions. (Bloom's 3-5)
2. Experiment Problems: These are based on apparatus. Students may be asked to do one or more of the following as part of their solution: add definition to the problem, plan a solution, divide a problem into sub-parts, make measurements, approximate or estimate, design an experiment, or figure out how something works. (Bloom's 3-4 , although if students are asked to design their own experiment, the level is probably closer to 5)
3. Jeopardy Problems: Jeopardy problems present the student with an equation, diagram, or graph, and then asks him to generate a physical situation that could have produced this representation. (Bloom's 3)
4. Problem Posing: In problem posing, students are given the beginning of a problem statement, and then asked to complete it so that a particular concept or principle must be applied in order for it to be solved. This approach forces students to think in terms of concepts, rather than equations (Bloom's 4 - 5 )
5. Ranking Tasks: . A ranking task presents several variations upon a situation and asks students to rank the situations according to a particular parameter, explaining their reasoning. (typically Bloom's 3 to 5 although one could envision complex situations requiring students to operate at level 6)
6. WRONG Problems: In these, students are presented with a problem statement and a possible solution for which they must identify and correct errors. (Bloom's 6)
7. Design & Build: In these types of laboratory experiences, students are asked to design an apparatus to perform a function. There are typically multiple ways to solve the problem. (Bloom's 5 to 6)

Engineering
In engineering, the students learn how to create ANSI standard engineering drawings using sketching and CAD. They also learn how to create three-dimensional models in CAD and extract orthographic multi-view drawings from the model. They learn how to do assemblies of multiple 3-D models. An important part of the engineering graphics is to help the students learn to visualize in three dimensions. Some problems give the student the pictorial and ask them to draw the three orthographic views. In these cases there is a single answer for the problem. More difficult problems give them two orthographic views and ask them to draw the third orthographic view and the pictorial. In general, there are multiple answers for these problems. Dimensioning the orthographic views provides a different type of problem where there are multiple ways to dimension an object following the ANSI guidelines.

In the programming aspect of the engineering sequence, the students learn how to write programs in C/C++ and MATLAB to solve a variety of problems. These include taking data during experiments and analyzing the data. In most of the programs that they write, they are given a specification of what the program should calculate and what the output should be. In these problems there are normally multiple ways to write the program.

Over the academic year (three quarters) the students work in teams on four design projects and in 17 hands-on laboratory exercises. One project is done in one period of 1 hour and 48 minutes, two are four-day problems, and the last one is a 10-week project where they design and build an autonomous robot. This project includes the planning, management, and documenting of the project. In the case of the design projects, there are multiple solutions to the open-ended problem given in the design specifications.

Mathematics
The focus in math is on solving real world problems, where they must think and apply their knowledge to solve the problem. They must understand the calculus at a deeper level than just manipulating equations. They need to work with functions in several forms, including formulae, graphs, and data tables. Many of the problems they solve include elements of those described above in the physics section, including realistic contexts and use of multiple representations in problem solving.

**Research Plan**
The authors are interviewing the faculty members teaching in the three disciplines to learn how the faculty members see the problem types in their disciplines. The authors are also reading the textbooks and other instructional materials to see whether they define problem types and, if so, how.. There are five textbooks required for the students in Math, Physics, and Engineering. They include texts for Calculus, Physics, C/C++ programming, Engineering Graphics, and MATLAB. The syllabi for these courses are also being reviewed. There are three physics courses, three engineering courses, and three mathematics courses.
From the literature and their own discussions about problem classifications, the authors will define problem types and then work on tying the problem types across the

disciplines. In this process they will look at the methods for solving the different types of problems.

An extremely critical part for this work is the development of different types of problems at different learning levels and sample solutions. Sets of problems and problem solutions are needed for each discipline. Just as different types of problems can take more time from the students to solve them, grading the problem solutions may require more time. The teaching team members will have to be trained/educated as to how to evaluate student work.

The authors will create an instrument(s) to determine whether students recognize that there are similar types of problems in the different disciplines. During the Winter Quarter 2005, the materials will be developed and used in the Spring Quarter. Students will be given the assessment instrument during the Spring Quarter 2005.

The two articles on the Intellectual Development of Science and Engineering Students (4,5) written by Felder and Brent in a recent issue of the *Journal of Engineering Education,* discuss the use of a variety of problem types and learning tasks to promote intellectual growth. They maintain that having the students solve a variety of problems with varying complexity during the undergraduate program can help promote intellectual growth through 'deep learning' rather than memorizing facts and solving single answer problems. Their components include "(1) variety and choice of learning tasks (including a variety of problem types), (2) explicit communication and explanation of expectations, (3) modeling, practice, and constructive feedback on high-level tasks, (4) student centered instruction (including active and cooperative learning), and (5) respect for students at all levels of development". The second article lists tasks that can be used in science and engineering courses and includes predicting outcomes, interpreting and modeling physical phenomena, creative thinking, identifying problems and trouble shooting for a process that is not working properly, formulate procedures for solving complex problems, and formulating problems. These suggestions fit well with the types of problems the physics instructors have been using.

**Results and Anticipated Results**

Faculty members from the three disciplines have been meeting on a weekly basis as part of the FEH program. Some time at these meetings has been devoted to discussing engineering and science education. There is an understanding that there are a variety of problem types but the interviews and teaching materials reviews will show where the common elements are contained. This definition of the problem types and where they are found along with examples will be presented.

The results of the student pre- and post assessment will be provided as part of the presentation. It is anticipated that the results will show that, with help from the faculty, that the students will be able to recognize the same problem types across disciplines and that they will have begun thinking in terms of 'problem types' rather than 'physics problems' or 'engineering problems'.

**Assessment Plan**

A. Develop the assessment instrument(s)
B. Collect the data
C. Analyze the data
D. Make adjustments to the instructional materials in all three disciplines

**Time Line**

A. Develop the plan – Winter Quarter 2004
B. Background Research in the literature – Autumn and Winter Quarter 2004
C. Interview faculty and review course materials in the three disciplines – Late Winter Quarter 2005
D. Develop the assessment instruments – Early Spring Quarter 2005
E. Develop the instructional materials and use in class – Spring Quarter 2005
F. Pilot the assessment – Spring Quarter 2005
G. Use problem type instructional materials in Engineering, Math, Physics Spring Quarter 2005
H. Evaluate pilot run of assessment tool– Late Spring and Summer Quarter 2005.

**Conclusions**

In the real world, the engineering students will face real problems that do not have simple answers. As part of promoting intellectual growth, students need to be able to recognize and solve a variety of problems. This process can start in the first year and it is proposed that having consistent presentations on problem solving from multiple disciplines will help the students recognize and be able to solve problems wherever they find them. The intellectual growth needs to continue throughout the undergraduate program and cannot start and stop at the first year. Developing a common set of problem types and set of problem solving instruction should help the students be much better prepared for the real world. It will also give instructors of upper-level courses a base upon which to build experiences to further this growth.

**Bibliography**

(1) Hughes-Hallet, D et al, *Calculus* (Wiley: NY, 1994).
(2) Knight, R. D., *Physics for Scientists and Engineers*: *A Strategic Approach* (Pearson Addison Wesley: san Francisco, 2004)
(3) Hsu, L., E. Brewe, T.M. Foster, K.A. Harper, "Resource Letter RPS-1: Research in problem solving," *American Journal of Physics*, 72 (9), September 2004, pp 1147-1156, and references therein
(4) Felder, R.M., and R. Brent, "The Intellectual Development of Science and Engineering Students Part I. Models and Challenges," *Journal of Engineering Education*, Vol. 93, No. 4, 2004, pp. 269-277.
(5) Felder, R.M., and R. Brent, "The Intellectual Development of Science and Engineering Students Part II: Teaching to Promote Growth," *Journal of Engineering Education*, Vol. 93, No. 4, 2004, pp. 278-291.

## Authors

JOHN T. DEMEL
John T. Demel is Professor of Engineering Graphics in the Department of Civil & Environmental Engineering. He coordinates and teaches for the First-Year Engineering Program. Dr. Demel earned his B.S.M.E. at the University of Nebraska (1965) and his Ph.D. (1973) in Metallurgy from Iowa State. He was the institutional Principal Investigator for the Gateway Engineering Education Coalition 92–03.

RICHARD J. FREULER
Richard J. Freuler is Associate Director of the Aeronautical &Astronautical Research Laboratory at Ohio State. He also coordinates the Fundamentals of Engineering for Honors. Dr. Freuler earned his BS in Aeronautical Engineering (1974), his BS in Computer Science (1974), his MS in Aeronautical Engineering (1974), and his PhD in Aeronautical and Astronautical Engineering (1991), all from Ohio State.

KATHLEEN A. HARPER
Kathleen A. Harper is a Senior Lecturer in Physics. Prior to joining Physics she was an Instructional Consultant with Faculty & TA Development at Ohio State. Dr. Harper earned her BS in Electrical Engineering (1993) and MS in Physics (1996) at Case Western Reserve University and her Ph.D. in Physics (2001) at Ohio State, specializing in physics education.