A New Integrated First-Year Core Curriculum In Engineering, Mathematics, And Science: A Proposal

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Introduction

Consider the development of a first-year curriculum in engineering, mathematics, and science as a problem. To solve the problem a formal problem-solving methodology will be used. First, the objective for the first-year curriculum will be presented. Second, the present solution to the problem will be examined. Finally, an alternative solution will be explored.

Problem Statement

The problem is to develop a first-year curriculum in engineering, mathematics, and science which will enable students to observe, describe, predict, and interact with the physical world. To learn to observe the physical world, students must assemble lenses (concepts) through which to view the physical world, e.g., energy, equilibrium, rate of change, and the capability of quantifying concepts, i.e., units. To learn to describe the physical world students must develop mathematical and graphics communications skills. To learn to predict behavior in the physical world students must acquire knowledge and facility with physical laws. To learn to interact with the physical world students must apply engineering design and problem-solving heuristics. An alternate problem statement would read: The objective of the first-year curriculum in engineering, mathematics, and science is to convey knowledge which will enable students to observe, describe, predict, and interact with the physical world.

Once the problem is stated, several observations can be made.

1. The problem is complex, i.e., it is beyond the capabilities of a single individual to grasp and solve the problem. Thus, any solution to the problem of developing a first-year curriculum must draw upon principles for solving complex problems.
2. There are two known principles to guide the solution of complex problems: decomposition and abstraction. The principle of decomposition recommends breaking the complex problem into simpler problems, solving the simpler problems, and constructing a solution to the original problem by putting the simpler solutions together. The principle of abstraction recommends combining the many, concrete problems within the complex problem into fewer, more abstract problems (since there are fewer problems, the overall problem is now less complex) which retain features common to the concrete problems. Concentrating on the fewer, more abstract problems will provide guidelines which simplify the solution of the more concrete problems. The two principles are used in any solution to first-year curriculum development.
3. If the principles of decomposition and abstraction are used in any solution to the curriculum development problem, then two basic questions arise. First, what guidelines or heuristics will be used when the complex problem is decomposed into simpler problems? Second, what common features will be emphasized when the more abstract problems are developed?

Traditional Solution

Specialization in engineering, mathematics, and science has produced recognized disciplines: mathematics, chemistry, physics, engineering graphics, computer science, engineering design, etc. When dividing the first-year curriculum into smaller areas of concentration, boundaries evolved so that each discipline had a recognizable problem. The problem of three-dimensional visualization is solved in a graphics course. The problems of quantitatively representing rates and areas are solved in a mathematics course. The problem of describing materials and their properties is assigned to a chemistry professor. The problem of applying physical laws is assigned to a physics professor. Use of computers is assigned to an introductory programming course. Finally, the problem of conveying design methodologies is assigned to an engineering design course. It should be noted that although divisions in the first-year curriculum were made by referring to recognized disciplines instead of referring to the objective of the first-year curriculum, the traditional approach has proved acceptable for many years.

However, there are a number of indications that weaknesses in engineering, mathematics, and science education are being recognized and ways to strengthen education need to be found. Several significant trends are noted below.

1. The Lean and Lively Calculus Conference [1] suggests that the first-year mathematics course - Calculus - devote time and effort to
   a. more modeling applications with *real world* complex problems,
   b. more problems in which computer solutions are an attractive approach,
   c. more discrete mathematics approaches, e.g., difference equations, and
   d. more multi-step problems which will involve and intrigue students.
2. The National Research Council (NRC) report in 1985 called for "the creative ability of engineering faculty members...to be focused on defining realistic goals for the education of undergraduates and then on *redesigning* (emphasis added) current programs to reach those goals."[2]
3. The National Science Board (NSB) report on Science and Mathematics Education in March 1986 cited the need for changes in science and mathematics education. It recommended that the National Science Foundation (NSF) expand its program in undergraduate engineering education.
4. NSF is increasingly aware of problems in undergraduate engineering education. In May 1986, NSF sponsored a workshop on Undergraduate Engineering Education. In May 1987, NSF held a workshop on Undergraduate Electrical Engineering Education. In the 1987-88 fiscal year, NSF has created an engineering curriculum enhancement program.

As isolated events, each workshop or report does not substantiate the need for bold, innovative approaches to undergraduate engineering, mathematics, and science education. However, as a group, these events display a nationwide concern for the state of undergraduate engineering, mathematics and science education and its need to improve.

Observations on the Traditional Approach

1. Undergraduate mathematics, science, and engineering education consists of separate courses in historically-developed disciplines. While students are performing well in individual courses, they are unable to relate concepts, techniques, and applications in one discipline to those in other disciplines. Given the *ad hoc* nature of the guidelines used to decompose the first-year curriculum, the observation should not be surprising.
2. Large disparity exists between current understanding of knowledge and current educational practice. Knowledge is interdisciplinary. Truly knowledgeable (or educated) persons can solve problems using information acquired in several disciplines. For example, yield optimization can be solved using chemistry, economics, and mathematics. Knowledge is holistic and synergistic. Understanding concepts, techniques, and applications in one discipline accelerates understanding in other disciplines. However, current educational practice puts knowledge into discipline-oriented containers called courses. Each course focuses on concepts, techniques, and applications which arise in its discipline, often ignoring relevant information students may have had in previous or concurrent courses outside the discipline. Further, a course usually does not consider applications outside the discipline. The discrepancies between the current perceptions of knowledge and current educational structures produce students who are inefficient learners and handicapped problem solvers. First, current curricula are organized to teach students fundamentals in separate disciplines. As a result, different disciplines use different terms or symbols for the same concept. Second, the pace of technological change is forcing undergraduate engineering, mathematics, and science curricula to include more and more material in four years. As a result, students have less time to reflect and integrate material. Third, students are rarely given any formal instruction on how to integrate concepts among disciplines. Without formal exposure to the process of integrating material from more than one discipline, time constraints force students to compartmentalize material. As a result, students fail to recognize relationships among the topics they are studying.
3. Failure to recognize relationships among concepts in different courses hinders students in two ways. First, each instructor must teach concepts from scratch. Therefore, the learning process is inefficient at a time when curricula are strained to include more topics. Second, students do not apply interdisciplinary approaches to problem-solving. Students choose an inefficient approach to a problem in one course, when application of techniques from a previous course in another discipline would have simplified the problem considerably. Failure to integrate material produces less efficient learners and less effective problem solvers.

Alternative Solution

Background

With a grant from Lilly Endowment, Inc., Rose-Hulman Institute of Technology is developing a new integrated first-year curriculum in engineering, mathematics, and science. Initially, the first-year curriculum was chosen for two reasons. First, the first year at Rose-Hulman is the foundation on which the individual programs of study are built. Second, students in the first year take a common curriculum (generally) of calculus, chemistry, physics, computer science, graphics, and engineering design. Superior preparation during the first year will encourage students to search for relationships and broad concepts throughout their engineering education.

Development of the new first-year curriculum started with four goals. First, the new first-year curriculum must be interdisciplinary. Second, it must be efficient, using designed coherent redundancy to reinforce concepts and techniques found in a number of the disciplines. Third, it must be adaptable, in order to identify, codify, and introduce fundamentals as technology continues to advance. Fourth, it must be visibly relevant and interesting in order to motivate students. Current efforts have concentrated on the second, fourth, and first goals.

In the proposed integrated first-year curriculum, ten (10) courses: calculus (3), chemistry (2), physics (2), graphical communication, computer programming, and engineering design, will be combined to create a one-year sequence of three twelve (12) credit courses. In fact, the collection of courses is more complex. Electrical engineers take two physics courses in the first year: PH125 Mechanics and PH135 Electricity and Magnetism. Mechanical and civil engineers take one physics course PH135 in the first quarter of the second year and two engineering mechanics courses: EM120 Engineering Statics (first year) and EM202 Engineering Dynamics (second year). Chemical engineers take EM101 Statics and PH125 Mechanics in the first year and PH135 Electricity and Magnetism in the second year. It is anticipated that the proposed first-year curriculum will satisfy all of the preceding requirements.

Alternative Curriculum

The alternative approach which has been developed is first to decompose the complex problem into generic or universal concepts and then focus the expertise and energies of disciplines to illuminate the capacity of the each generic concept to observe, describe, predict, and interact with the physical world. Generic concepts which have been identified in the present exploration of the first-year curriculum include data acquisition and analysis, problem-solving techniques, functional relationships, equilibrium, rate of change, force, work and energy, and momentum. Developing an alternative first-year curriculum organized along the lines of generic concepts requires several steps. First, the generic concepts must be identified. Second, links between disciplines and generic concepts must be established. Third, skills or techniques necessary to use the generic concepts must be identified. Fourth, applications or problem situations in which students apply the generic concepts must be presented to the students. The fourth step creates opportunities to use the concepts and skills to observe, describe, predict, and interact with the physical world.

Consider the first generic concept: data acquisition and analysis. It encompasses concepts such as physical quantities: mass, force, temperature, and charge, which are abstractions with which students will observe the physical world. Following an introduction to physical quantities is the concept of units which enable people to share observations of physical quantities. Finally, data presentation, including significant figures, units, charts, and graphs, allows students to effectively communicate the results of experiments.

Problem-solving is the second generic concept. Traditionally, first-year curricula have developed problem-solving ability by using the dreaded assignment, written problems. However, problem solving is simultaneously narrower and more inclusive than written problems: Solving written problems requires the following problem solving skills: the ability to recognize relevant information, the ability to identify the important variables, the ability of extract quantitative relationships from text and express them mathematically, and the ability to solve the resulting set of equations. Problem-solving also includes more general skills: problem definition, formulating a strategy for solving a particular problem, creatively generating alternate solution strategies, and selecting a solution strategy. All of the above skills will be developed more carefully and more thoroughly in the alternative curriculum.

The third generic concept, functional relationship, allows students to abstract and to describe quantitatively relationships in observed phenomena. As a starting point, students learn how a function defines a relationship between two variables. Students recognize connections between functions expressed by formulas and functions expressed graphically. Next, students can construct functional relationships for data obtained from an experiment by graphing the data, hypothesizing a functional form, selecting an *optimal* parameter set, and, finally, comparing the fit between the measured data and the predicted functional relationship. Expressing functions of two or more variables using equations and surfaces is the next step. Finally, students will model physical phenomena. From their observations and knowledge of physical quantities (see first generic concept, data acquisition and analysis), they will select relevant variables, hypothesize functional relationships, select an *optimal* parameter set, and then compare the measured data to the predicted functional relationship.

Consider the fourth generic concept of equilibrium. First, two types of equilibrium are recognized: static equilibrium and dynamic equilibrium. A system is in static equilibrium if all rates of change are zero. Alternatively, a system is in static equilibrium if it has reached a minimum of maximum of potential energy. Applying the concept of static equilibrium to engineering statics, a student would define static equilibrium by requiring that the linear and angular accelerations are zero. (Alternatively, a student could require that the rates of change of linear and angular momentum are zero.) Using Newton's second law, students would find static equilibrium by setting the net force to zero and setting the net moment to zero. In a problem involving gravitational and electrostatic forces a student could find static equilibrium by equating gravitational and electrostatic forces. Another student could search for positions where the sum of the gravitational and electrostatic potential energies are at a minimum or a maximum. A system is in dynamic equilibrium if the net rate of change is zero. Dynamic equilibrium is characterized by an equilibrium constant which allows students to calculate concentrations of reactants and products when the reaction is in dynamic equilibrium. Requiring that a system be in equilibrium allows students to bring several different tools to bear upon the problem.

Another generic concept is rate of change. Rate of change appears in physics concepts of velocity and acceleration, in chemistry in the study of reaction kinetics, in mathematics as the derivative, in optimization problems by requiring the rate of change to be zero, and in small-signal models (also read linearization) where nonlinear relationships are approximated by their rate of change at a specified operating point. As was seen in the discussion of equilibrium, rate of change is a concept prerequisite to the concept of equilibrium.

Therefore, the new core curriculum will build on concepts which naturally span the disciplines of mathematics, computer science, chemistry, physics, graphics, and engineering design through classroom instruction, laboratory experiments, and extended projects, all designed to enable the students to build a stronger conceptual foundation for their future engineering education.

Implementation

Curriculum change cannot and must not occur overnight. As the task force of the Engineering Deans Council noted, "The best tactic for strengthening undergraduate curricula appears to be well-planned educational experimentation. New conceptual approaches should be systematically tested."[2] To successfully implement any change, there is a need for gestation, incubation, comment, and revision of ideas in order to develop common understanding and consensus. Contributions and suggestions must be sought from different disciplines, from different constituents of the Institute, from different institutions, and from industrial advisors. Preliminary pedagogical experiments should be conducted in order to evaluate the viability of the approach. In summary, significant curricular change requires a long-term commitment from the Institute, a plan for implementation, and significant resources.

A three-year, multiple phase approach to planning, developing, and implementing the new integrated first-year core curriculum has been developed. In the first phase (August 1988-May 1989), a preliminary syllabus will be prepared during the summer of 1988 by six faculty members. During the academic year, it will be presented to Rose-Hulman's faculty, students, and administration, the Rose-Hulman's National Board of Advisors, the 1988 Frontiers in Education Conference, and the 1989 ASEE Conference for comment and revision. In the second phase (June 1989-May 1990), the working form of the new core curriculum will be produced during the summer of 1989 and taught to approximately one-third of the 350 first-year students during the 1989-90 academic year. The entire class of 350 students will be monitored in their sophomore, junior, and senior years to evaluate the impact of the integrated first-year curriculum. In the third phase (June 1990-May 1991), the response of the students, faculty, and external constituencies to the core curriculum will be summarized and evaluated. Then, the core curriculum will be taught to the entire first-year class. If the new core curriculum is successful, then it will become the standard curriculum for first-year students at the Institute.

Status

At present we can make the following observations: We have produced an integrated, sequenced curriculum in which mathematical concepts unfold in a traditional order, i.e. differentiation followed by integration. The chemical portion of the curriculum is very similar to the present chemistry courses, but the topics are coordinated with the rest of curriculum. The physics portion of the curriculum has been revised to incorporate mechanics, statics, dynamics, and electricity and magnetism and to coordinate its topics with the rest of the curriculum. The design element recurs throughout the curriculum, starting with simple design projects and little analysis, and finishing with complex design projects with analytic support and *audience* writing reports.

Important links between the disciplines have been recognized. Three-dimensional graphical visualization will be introduced by the use descriptive geometry and orthographic projections and will be an important aid when students start finding volumes of revolution by disks and shells. When forces are introduced, examples will include not only gravity and friction (standard fare in a mechanics course) but also buoyant force, electrostatic force, and (possibly) magnetic force. Work and energy (physics perspective) will be coordinated with thermochemistry (chemical perspective) and support discussion of conservation of energy for rigid bodies (usually discussed in dynamics). Electrostatic potential, normally a very difficult concept for students (and faculty members outside the physics department) to grasp, will be taught in parallel with gravitational potential, which can be easily visualized by use of a topographic map. Programming, spreadsheets, and computer algebra systems will be integral parts of the students' problem solving tool kit. Design problems will be linked to analytical methods presented in the rest of the first-year curriculum.

Conclusion

At this stage of the project, the six individuals, all of whom agree there is a need for reform and that an integrated first-year curriculum is one viable way to achieve the goals of a solid engineering, mathematics, and science education programs, have spent a good portion of the summer together. They have discovered common areas of cooperation and interface between their traditional backgrounds and they have uncovered some very unique opportunities to integrate ideas and skills found in disciplines under one or more of the broad generic concepts described above. At times there has been friction and disagreement about topics, pedagogy, sequencing and timing, and prerequisite information and skill levels. But thus far, a sense of, "This can really happen!" has emerged from the group.

We now begin our efforts to secure comments and critiques from our various Institute constituents and public forums. We are anxious to hear from you.

Copies of the "in progress" syllabus will be available from the authors upon request.

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- Michael Moloney, Professor of Physics
- Edward Mottel, Associate Professor of Chemistry

A wider Presidential Commission (of 13 faculty and staff members) will be meeting throughout the academic year 1988-89 in support of the project.

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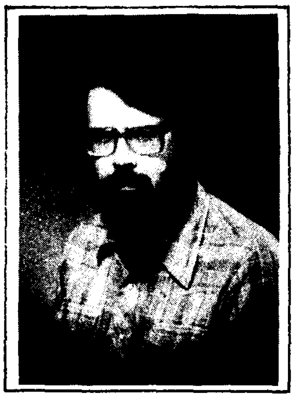
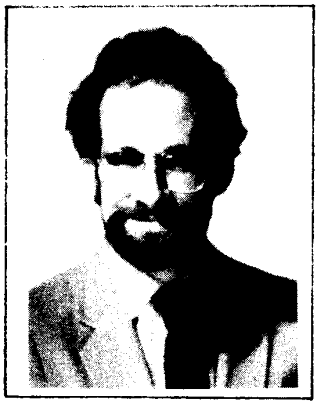


BRIAN J. WINKEL

Brian J. Winkel benefited from a traditional undergraduate liberal arts education and after receiving his PhD in algebra from Indiana University in 1971 he took his first teaching position in a liberal arts school. Upon coming to Rose-Hulman Institute of Technology in 1981, he began to learn about the mathematical needs of engineering students and the traditions of the engineering curriculum. He found that students enjoyed challenging, unstructured, and sometimes open ended problems, but that the curriculum had to adjust for such activities. At the same time he found that students were not relating concepts taught in the various areas of their curriculum. He was pleasantly surprised when he found collegial support for reform to permit the former explorations and to address the latter problem. In addition to his teaching, Professor Winkel edits two international journals, *Cryptologia* and *Collegiate Microcomputer*.



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