An Integrated, Project-based, Introductory Course in Calculus, Physics, English, and Engineering

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Abstract:

Arizona State University is a member of the NSF-sponsored Engineering Education Coalition known as the Foundation Coalition. This paper describes the development of an integrated introductory course delivered to freshman engineering students at ASU in the Fall '94 semester as a part of the Foundation Coalition program.

The course combined and integrated material from introductory courses in calculus, physics, English composition, and engineering, normally taught in a stand-alone format. The calculus used in this course was based on the ''Harvard reform model'' and include d a review of functions, the derivative, the definite integral, and application of these topics to physics and engineering problems. The physics was mechanics-based, with emphasis on kinematics, dynamics, conservation principles, rotational motion, and re lativity.

What differentiated this integrated package from versions found at other institutions in the Coalition was (a) the inclusion of English composition, and (b) the project-based introduction to engineering. In this integrated course, the students learned to organize and develop ideas for both technical and general audiences. In addition, they learned the use of rhetorical principles with readings from the philosophy of science, engineering case studies, and so on.

The over-arching framework for the class was the use of engineering projects to teach design and modeling principles. The three projects incorporated the calculus and physics that had been learned to date in the class. The first utilized kinematics and curve-fitting to functions to design and build a simple projectile launcher; the second employed dynamics and numerical integration to design and build a bungee drop system; and the third project, which also served as the final exam, used rotational motion concepts and a data acquisition system to identify the shape and material of a hidden object.

The integrated course also employed considerable use of computers in an active learning environment that stressed teaming and other quality tools.

I. Prototype First Year Curriculum at Arizona State University

Arizona State University is a member of the NSF-sponsored Engineering Education Coalition known as the Foundation Coalition. Foundation Coalition member institutions are Texas A &M University (lead), Arizona State University, Maricopa Community College District, Rose-Hulman Institute of Technology, Texas A &M University at Kingsville, Texas Woman's University, and the University of Alabama at Tuscaloosa. The fundamental thrust of the Foundation Coalition is to provide a new engineering education culture which incorporates an integrated curriculum, taught with active learning strategies using technological enhancements wherever possible. To initiate this cultural change, a curriculum experiment on the ASU campus has begun with the implementation of a Freshman Integrated Program in Engineering (FIPE). In the Fall '94 semester the elements of ENG101 (First Year English Composition), PHY121 (University Physics I), PHY122 (Physics Laboratory I), MAT270 (Calculus I), and ECE100 (Introduction to Engineering Design) were integrated together under the schedule shown in Figure (1). Within the contact hours shown in this figure, material could be and indeed was moved around to provide the best coordination of subject matter.

The student body for the FIPE program consisted of 31 volunteers, recruited from incoming freshmen admitted to the College of Engineering. Their declared majors are shown in Fig. 2. Twenty-nine students came directly from high school, while two ''older students'' had either worked or served in the armed forces before pursuing their BS degree in engineering. The composition of the group was 6 women (all Caucasian), 6 male minority students (5 Hispanic and 1 African-American), and 19 Caucasian males (Fig.3).

Begin Time	Monday	Tuesday	Wednesday	Thursday	Friday
7:40	ENG 101		ENG 101		ENG 101
8:40	MAT 270	PHY 122	MAT 270	MAT 270	MAT 270
9:40	PHY 121	PHY 122	PHY 121	PHY 121R	PHY 121
10:40	ECE 100	ECE 100	ECE 100	ECE 100	ECE 100
11:40			ECE 100		

Figure 1: Class Schedule for FIPE

The vehicle for establishing the integrated curriculum was the University Campus Match program in which a cohort of students registers for a common set of courses and attends special sections only available to the Campus Match. Thus, the students in the FIPE program registered for 15 hours and attended all of the classes as a unit.. The only exception to this for the engineering Campus Match was in ENG101 where seven students had prior credit or advanced placement credit for the course.

Figure 2: Class Composition by Ethnicity and Gender

Training in team skills and cooperative learning began in the second hour of the first class on the first day of the Fall semester. Approximately eight hours of the total of 19 contact hours during the first week of class were devoted to structured activity designed to train students in team dynamics. Additional training modules were given each time new teams were formed, which coincided with the start of each major project.

Figure 3: Class Composition by Major

Integration took the form of identifying as many ‘‘cross-links’’ as possible among the constituent subjects then arranging the order of presentation within the various disciplines to present the cross-linked topics in a mutually reinforcing fashion. The curriculum emphasized computer instrumentation and technology. Many of the course activities were carried out as team efforts. Active and cooperative learning teaching methods were used extensively.

The calculus used in the FIPE was based on the ‘‘Harvard reform model’’ and included a review of functions, the derivative, the definite integral, and application of these topics to physics and engineering problems. The physics was mechanics-based, with emphasis on kinematics, dynamics, conservation principles, rotational motion, and relativity. The engineering included concepts of design, introduction to modeling, and concepts of visualization through sketching and CAD.

One of the things that differentiated this integrated course from versions found at other Coalition institutions was the inclusion of English composition. In this part of the FIPE, the students learned to organize and develop ideas for both technical and general audiences. Throughout the semester, the students kept detailed journals describing (through directed journaling assignments) their reflections on the science and engineering concepts from the other portions of the class. Written reports were submitted for all of the engineering projects, including the final examination project. The reports were graded for exposition, style, clarity, and grammar by the English instructors. In addition, they learned the use of rhetorical principles with readings from the philosophy of science, engineering case studies, and so on.

II. Class Projects

The over-arching framework for the class was the use of engineering projects to teach design and modeling principles. This framework was one indisputable success in the class. The three projects incorporated the calculus and physics that had been learned to date in the class.

The first project involved the design and calibration of a squash ball slingshot. Working in teams of four, students digitized video images of the squash balls fired from their slingshots and parameterized the trajectories for given initial extensions of the slingshot bands. This project made extensive use of mathematical functions, curve fitting and electronic spreadsheets. As this project neared completion it blended nicely into physics discussions of kinematics and 2D trajectories. The project culminated in a competitive shoot-off to test the students' design and analysis skills.

Project number two was a bungee-cord egg drop. More details on this project, as well as the ASU Foundation Coalition program, are available on the World Wide Web at **http://www.eas.asu.edu:80/asufc/** (Note to reviewers: this project is currently being added to the ASU's Foundation Coalition homepage and will be available before the FIE conference). Students, again in teams of four, made stress/strain measurements on one meter lengths of a rubber cord sample (the bungee material to be used), then used electronic spreadsheets to model the physics of the drop using their material property measurements in the model. They had to pick the number of strands and the length of cord to meet two goals: (1) to have their raw egg (dropped from an initial height of 18 meters) approach the ground as closely as possible without breaking the egg, and (2) to have the maximum deceleration of the egg never exceed a specified value. The teams also had to design a release mechanism for launching their egg. Again, the designs were tested in a contest format at the end of the project. On final jump day, the students had to present the specifications of their cord to the instructors who manufactured the cord on the spot. The bungee drops were then done immediately. In only one of eight designs did the egg break on impact with the ground. In one design the egg ‘‘kissed the ground,’’ but did not break. The other six missed the ground from a centimeter to about 60 centimeters.

Each bungee jump was video taped in Super8 format and then digitized using video capture boards in their computer workstations. The digitized images were played back, frame by frame, and the spatial coordinates of the egg in each frame were measured using the CUPLE software obtained from Rensselaer Polytechnic Institute (RPI). The resulting displacement versus time data were transferred to spreadsheets and curve fit and differentiated to give velocity versus time and acceleration versus time. This allowed each team to verify that their egg did not decelerate more than the specified value. The bungee spreadsheet models were later analyzed in a physics lab for conservation of energy, offering a rich display of energy flowing back and forth among gravitational potential energy, spring potential energy, kinetic energy, and dissipation into thermal energy.

The third project, using the apparatus described by Amato [1], actually comprised half of the final examination. Students were given opaque spherical plastic shells, each containing one of three possible shapes (cube, cylinder, or hollow cylinder) constructed of either aluminum or brass. The spheres could be spun about any of three orthogonal axes and the angular acceleration measured using a Pasco Scientific ‘‘Smart Pulley’’ read into a Macintosh computer via a Vernier Software ‘‘Universal Laboratory Interface.’’ The problem was underspecified and successful identification of the unknown shape thus demanded not just the obvious physics and math but also critical engineering contemplation of the values which were obtained from the measurements.

The student teams were given five hours to carry out this project. They were first expected to determine the process that would lead them to a successful result. They needed to contemplate the relevant physics for the problem (angular acceleration, moments of inertia, connection of linear and angular motions, etc.); they needed to train themselves quickly with unfamiliar software and hardware; they needed to make initial measurements, use engineering estimates to toss out shapes or materials that were infeasible; they needed to refine the measurements and analysis; they needed to arrive at a conclusion; and finally, they needed to record the entire process and their conclusions in a word processed document. Of the eight teams that participated, three successfully identified the shape and material of the hidden object, and two were able to make reasonable estimates of the object's dimensions. Even the teams that were unsuccessful in the identification made plausible conclusions based on their data and analysis.

III. Technology Enhanced Education

The engineering and science portions of the FIPE program were taught in a ‘‘high tech’’ classroom that had eight square team tables, each seating four students. Each team had access to two computers located on separate tables around the periphery of the room. As a team needed to access the computer, two of the students could rotate their chairs and the other two could roll their chairs around the work table so that all students could surround the computers. One of the computers available to each team was a Windows-based PC and one was a Macintosh Quadra. All the computers had CD ROM players and sound capability. Half of the PC computers had an Intel Indeo video capture card installed for digitizing video. In addition, all computers were connected to the campus ethernet, giving full, high-speed connection to the INTERNET. The computers, through the ethernet network, were connected to a network server and a PostScript compatible laser printer.

All of the students were expected to learn and use both Macintosh and PC platforms. This was also an unqualified success: within weeks, the students were able move back and forth between platforms effortlessly. Software available to the students included word processors, spreadsheets, presentation graphics, symbolic math and computer algebra packages, CAD, data acquisition and related transducers, physics demonstrations, graphing programs, software for digitizing and playing video, electronic mail, and INTERNET utilities.

The support equipment for instructors included both a PC and a Mac (both comparable to the student machines), a video cassette recorder/player, a laser disc player, a pad camera, and a Proxima 2800 projector that handled both data and video (with sound). Thus, any variety of material could be displayed on a large screen in the room, from the instructor’s computer screen image to video tapes and laser discs to hard copy of material to be displayed. There was also the conventional overhead projector and ‘‘white’’ boards.

In addition to all of the equipment described above, the instructors’ PC had video conferencing capability. Students or an instructor could ‘‘dial’’ up the Foundation Coalition main office in the engineering office and video conference with the administrative assistant or the project coordinator and vice versa. This capability is also being extended to the offices of the teaching faculty, as soon as some technical difficulties can be worked out.

IV. Assessment and Evaluation

To assess the impact and effectiveness of the FIPE program, a comparison group of students who were registered in nearly the same set of courses and had similar levels of prior academic achievement, was defined using a database software system that allows queries and data extractions to be made from ASU’s student data base. This data base contains all pertinent data on students, courses, and performances.

Performances of the students in the FIPE program have been compared with those of similar students who took the same content in a traditional curriculum. These comparisons include earned grades in each of the elements and attrition rates. In addition, the FIPE students were assessed in the areas of critical thinking, knowledge of fundamental concepts, attitudes toward courses in math, science, engineering and English, and attitudes toward engineering as a profession. In addition, it will be possible to compare attrition rates, and in subsequent years to compare performances in downstream courses.

The following assessment tools were also used during the course of the FIPE:

- Hestenes Force Concepts Inventory[2] - Given as both a pre and post test
- Hestenes Mechanics Baseline Test[3] - Given as both a pre and post test
- California Critical Thinking Skills Test - Form A[4] - Given as a pre test
- California Critical Thinking Skills Test - Form B[5] - Given as a post test
- Learning Styles Survey[6]
- +/Δ Process Checks - Given weekly or bi-weekly
- Three special questionnaires during the semester

Preliminary data show several things:

- All 31 students who started the FIPE program on the first day of class attended throughout the semester and took the final examination - there was no attrition during the semester.
- Failure rates in the first semester in the FIPE were far lower than those shown by comparable students in the traditional program, as shown in Table I. First semester student attrition is shown in Fig. 4. Three students, all male Caucasian, failed parts of the course (1 failed calculus, 2 failed physics, and 1 failed English) and could not register for the second semester of the FIPE program because of lack of prerequisites. Four students, three male Caucasians and one minority, chose to leave the program and try the traditional route of courses as stand-alone modules, although they had passed all parts of the FIPE. Two of these were very good students academically, but were not enthusiastic about the team emphasis in the FIPE program and/or the Harvard calculus (see anecdote 3 below). One female student returned for the second semester solely because of the FIPE, but decided that she was homesick and returned to her home state. All students who did not continue on in the spring FIPE are still enrolled in engineering at this writing.
- Students in the FIPE program had about a 30%better improvement on the Hestenes Force Concepts Inventory Test than shown by Hestenes' data on traditionally taught students.

Figure 4: Student Retention and Attrition

Table 1: Percentage Withdrawals and Failures

Course	Campus Match (FIPE)	Similar Students (in same classes)
ECE 100	0	15
PHY 121	6	14
MAT 270	3	25
ENG 101	3	10

Anecdotal data demonstrate the following:

1. Exceptionally strong bonding occurred among the students.

2. Some students who started slowly/poorly gained confidence and became good students later in the class as instructors and fellow students gave support. There is a high probability that such students would have encountered trouble in traditional classes.

3. Students who tried to ‘‘live off’’ their high school calculus (of traditional format) did not do as well as the students who adopted the Harvard-reform calculus viewpoint early.

V. Future Plans

A second semester continuation to the FIPE program described above was offered in the Spring’95 semester. The courses integrated in the second semester combined the elements of ENG102 (First Year Composition II), PHY131 (University Physics II: Electricity and Magnetism), PHY132 (University Physics Laboratory II), MAT271 (Calculus II) and CHM114 (General Chemistry for Engineers). A similar schedule of classes to that in Figure (1) was used, with the chemistry course replacing the engineering hours. The results of this continuation to the FIPE program will be described elsewhere.

A prototype sophomore integrated program will be offered in the Fall ’95 and Spring ’96 semesters. The following courses will form the Fall 1995 Foundation Coalition curriculum at Arizona State University: MAT274 Elementary Differential Equations (3 hrs), MAT342 Linear Algebra (3 hrs), ECE301 Electrical Networks I (4 hrs), ECE394 Mechanics (4 hrs), ECN394 Applied Microeconomics (3 hrs). Material in these courses will be integrated together under the general theme of systems behavior or systems modeling, using common ideas, terminology, and concepts. The formal scheduling of the courses will resemble that for the FIPE program, but faculty will be free to move material around within these contact hours.

To support the scale up of the FIPE program and the sophomore program, in the Fall semester of 1996, two adjacent classrooms in the Engineering Center will be combined into a large cooperative learning classroom which will seat a maximum of 80 students. The furniture will include rectangular tables and swivel chairs on rollers. The room is scheduled to be complete with instructor’s podium giving access to multimedia presentations. Engineering will proceed to equipment this room with computers for students, with 1 computer for every two students.

Acknowledgments

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