New Paradigm for Foundational Engineering Education

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Abstract

In fall 2004, implementation of a significant redesign of the first semester introductory engineering course (EngE1024) required for all first-year engineering students at Virginia Tech, has occurred in support of a shift in paradigm: 1) the enhanced research mission of the new Department of Engineering Education and 2) administrative restructuring that led to inclusion of Computer Science students in the College of Engineering. This redesign resulted in changes to course curriculum and coordination and hiring/management of faculty.

The increased focus on educational research has had multiple effects on EngE1024, including the incorporation of outcomes of ongoing research projects, such as the incorporation of electronic portfolios for assessment and reflection purposes originated from an NSF Bridges to Engineering Education grant and use of a 'spiral curriculum' approach from an NSF Department-level Reform grant.

The change in paradigm resulted in significant personnel changes. For the first time, the department hired graduate and undergraduate teaching assistants to aid in course development and implementation. Also, to provide faculty time to develop research programs, an unprecedented number of adjunct faculty were hired to reduce the teaching load of the regular faculty. The sheer number of faculty and teaching assistants created new management challenges.

This paper documents a major shift in one of the largest freshmen engineering programs in the United States and the noteworthy affects this is having on its first semester engineering course.

Background

In 1968, the Virginia Tech College of Engineering created the Division of Engineering Fundamentals, which was assigned to teach, mentor, and advise freshman engineering students. At Virginia Tech, all freshman engineering students enter as General Engineering (GE) students and are transferred to a degree-granting department when they have successfully completed a required set of courses.

Over the past seven years, the first-year courses have evolved from somewhat standard problem solving, graphics, and programming courses to a format that emphasizes early design and realization, collaborative learning, and highly interactive classroom environments[1,2,3,4]. Virginia

Tech engineering (computer science) students have been required to own personal computers since 1984 (1985). In fall 2002 College of Engineering (COE) required laptop computers, which were immediately incorporated into the classroom environment. Faculty and students quickly saw an improvement in the teaching and learning of software (including Matlab and Autodesk Inventor) in the first-year courses.

In summer 2003, the Department of Computer Science (CS) joined the COE, and it was decided that CS bound students should also take freshman year engineering courses like GE students. Further, a decision has been made that entering freshmen interested in computer science should begin as General Engineering (GE) students in Fall 2005. Total enrollment in the first class was approximately 1250 students. The first engineering course was redesigned to accommodate both engineering and computer science bound students. The primary problem with the existing course was that instruction using Matlab, which is inherently procedural, was viewed as an inappropriate first programming experience for computer science and computer engineering students, who will ultimately program in Java and C++, respectively. Moving directly into an object-oriented programming (OOP) environment was desired.[5,6]

Design of the new course involved faculty from all engineering departments, with computer science and electrical & computer engineering being more involved since the primary change was at their request. After considerable discussion a syllabus was arrived at that involves general problem solving, ethics (formerly engineering ethics, now expanded to include software considerations), visualization of 3-D objects and also visualization of information, early design (including realization), graphing and simple analysis of graphs, and OOP. The OOP language Alice (www.alice.org)[7] was chosen because of its inherently syntax-free nature. The new course, designated EngE 1024, Engineering Exploration, was offered for the first time in Fall 2004.

Course description

The course description is: "Introduction to the profession and the College of Engineering; foundation material in: problem definition, solution and presentation; design, including hands-on realization working in teams; modeling and visual representation of abstract and physical objects; scientific computation; algorithm development, computer implementation and application; documentation; ethics; professionalism".[8]

The course was 2 semester hours, meeting twice a week for 50 minutes.

Course objectives

One of the objectives of the course redesign was to retain as much of the existing course material as possible, since it has been quite successful. Computer Science was very willing to have their freshman students participate in the hands on activities, which tend to be somewhat mechanically oriented. The official learning objectives of the EngE1024 were:

Having successfully completed this course, the student will be able to:

- demonstrate a basic understanding of the design process;
- demonstrate basic facility with hands on design and design evaluation, accomplished by working in teams;
- demonstrate a knowledge of the disciplines of the Virginia Tech College of Engineering;
- demonstrate an understanding of professional ethics and application to real-life situations;
- apply the scientific method to problem solving including use of software where applicable;
- graph numeric data and derive simple empirical functions;
- develop and implement algorithms that focus on object oriented approaches;
- describe basic concepts associated with working in teams.

It should be noted that though the list of learning objectives appears quite long for a two-credit course a number of the objectives are actually covered simultaneously in particular exercises and assignments. That became apparent as we broke down the objectives and created the outline of the course syllabus. The topical coverage is shown in Table 1.

TABLE 1
OUTLINE OF COURSE SYLLABUS

Topic	% of course
Introduction to and application of the design process • Introduction • Design projects • Hands on work in teams	25
Disciplines of the Virginia Tech College of Engineering	10
Professional Ethics	10
Applying the scientific method to problem solving • Application of basic physical and mathematical concepts • Translation of word problems to mathematical statements • Sketching	15
Graphing numeric data and deriving simple empirical functions	10
Developing and implementing algorithms • Visual representation of abstract objects • Develop object-oriented algorithms • Computer implementation	30

<u>Alice</u>

As Alice had never been used by such a large engineering population prior to this course, the course coordinators and teaching assistants worked in close collaboration with Alice developers at Carnegie Mellon, St. Josephs, and Ithaca College to develop Alice instruction material. All of the Alice lessons necessitated the use of laptop computers by the students. Each classroom had not only an instructor but also one or two undergraduate or graduate teaching assistants who were proficient in Alice programming. These classroom teaching assistants were required to help students submit software-related bugs to the Alice development team as well as answer questions students had during in-class exercises. Weekly lessons of Alice involved three parts: (1) readings associated with the week's lessons and downloading the latest version of the software prior to the first lecture of the week (2) lecture containing new programming concept(s) with hands on exercise (3) continuation of week's concept with hands on exercise and appropriate homework assignment. Weekly lessons covered the following topics: objects, methods, parameters, storyboarding, selection structures, and loops. Through self-study, students were also encouraged to learn and use: events (using keyboard or mouse strokes to initiate code), sound as part of their programs, and tools to facilitate sharing of code for a team-based Alice project. For the first time, a team-based programming project was part of the syllabus. Students worked in teams of 3-5 students to generate a computer game that was presented to and evaluated in part by their peers. Also, unlike previous semesters, instructors were encouraged to grade programming assignments during class. Alice is a very visual programming environment which eases grading. Details of Alice instruction are presented in a companion paper.[9]

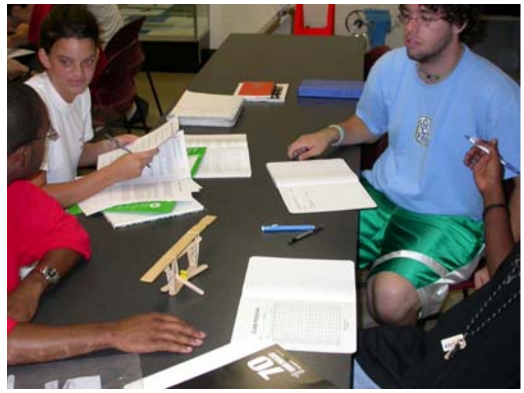
From the viewpoint of the department head, implementation of Alice has been fairly smooth. One of the worries of administrators is always cost to the students, whether the expense be books, software, or materials. Since Alice is free, cost to students was a non-issue. In addition, instructors told the students up front that they were part of the development process for Alice, which was appropriate since one of the learning objectives in the course is introduction to design as a process. Then the students had the sense that they were part of the "team" that was doing the final shakeout of Alice before it moves to the next level. Given the free software, and the knowledge that the software was in development, relatively few complaints were voiced when bugs were encountered. With 43 sections of the course (each with approximately 30 students), the cost of hiring the undergraduates for classroom instruction cost the department approximately $2,000 over the course of one semester.

One always hears anecdotal evidence in such situations. Several faculty who encountered students "playing" with Alice, creating worlds and simulations just for the fun of it. Some students tried to create rudimentary video games. Educators should jump for joy when they discover students "playing" with a tool they have introduced to them, for it is that playtime that often leads to self-directed, experiential learning that goes beyond the course objectives and turns the students into active learners just for the sake of knowledge. It does not get any better than that.

<u>Hands on, collaborative learning</u>

Considerable work has been done on the first semester course over the past few years with the goal of introducing early design, realization, and collaborative learning. MacGyver projects[4] and in-class activities that promote active learning continued to be an important part of the syllabus. Since a substantial part of the course was based on group work, teamwork was emphasized at the beginning of the semester. During the first lesson, students were taught effective teamwork strategies and engaged in a related exercise; students were asked to individually rank items for survival in a fictitious desert scenario and then rank the same items with a group of students. In the second lesson, groups of students participated in a design-build exercise in a short openended project in which they were given materials and instructions to create something useful and interesting (Figures 1 and 2); the groups were also required to present their prototypes and generate an evaluation matrix as a class.


(1)


(2)

Figures 1 and 2. Students are working in teams of four to create a simple prototype.

For the first time, students were required to use the West Point Bridge Designer[10] software as well as construct and test a truss design. Incorporation of this project into the curriculum originated as part of a Ph.D. research project of a student in the Department of Teaching and Learning.

Projects not only engaged the students in the design cycle but they also emphasized the importance of technical communication. For the MacGyver and Alice projects, students were required to generate an accompanying written report.

Impact of enhanced research mission

The newly formed Department of Engineering Education was previously known as the Division of Engineering Fundamentals; in the past, the primary mission of the division was to advise freshmen students and to create and teach modern, first-class introductory engineering courses. In addition to these activities, the new Department now offers graduate courses and has increased educational research. To allow faculty time to generate new graduate programs and to pursue more research activities, the teaching load was reduced from four sections to three sections per instructor.

Since many of the instructors are also advisors to engineering freshmen, the coordinators elected to introduce an "advising issue of the day" as part of the lessons; some advising examples include: addressing emails properly, on-campus job fair announcements, and the Virginia Tech honor code. The advising issues were intended to reduce the number of times advisors relayed the same information many times to multiple students and to allow faculty to use time more effectively by concentrating on research activities. For students, this was a way for the students to gain insight into resources available to them as students at Virginia Tech; some of these resources involved centers to improve writing, workshops to strengthen study habits, and peer tutoring for classes common to freshmen engineers. Students were also required to attend a lecture by the college of engineering dean's office regarding administrative policies.

Part of the enhanced research mission involved creating and administering a variety of assessment tools. Students were asked to take multiple surveys to assess learning styles, demographic information, pre-college experiences, and attitudes regarding computers, teamwork, projects, coursework, etc.

For example, the computer attitudes survey revealed that 40% had studied one or more programming languages and over 80% agreed when asked: "Using computers to write programs is a creative, logical pursuit of finding solutions to problems where the pieces can fit together in many, different, innovative ways" but less than 10% agreed when asked questions like: "I'm not the type to do well with computers," "I will do as little work with computers as possible," "I expect to have little use for computers in my life (3%)," "Learning about computers is a waste of time (2%)".[9]

Additionally, application of Dr. Richard M. Felder's Index of Learning Styles[11] to approximately 1250 freshmen revealed the following results:

66% of students were active learners (as opposed to reflective)
63% of students were sensing learners (as opposed to intuitive)
85% of students were visual learners (as opposed to verbal)
65% of students were sequential learners (as opposed to global).

Considering these results, the changes to this engineering course appear to be appropriate, with increased visual aids, hands-on experiences, etc. The Index not only allowed the students to gauge their learning styles and reflect on ways to enhance their educational experience but also increased awareness among faculty regarding ways to help different types of learners that exist in the classroom.

Students also consented to share Alice projects as well as electronic portfolios; the latter will be useful as a long term assessment tool.

Within the last two years, the Department received several grants including an NSF Bridges to Engineering Education grant and an NSF Department Level Reform grant. As part of these grants, the notion of a spiral curriculum and course-wide use of an electronic portfolio were introduced into the first semester course.

<u>Spiral curriculum</u>

Spiral curriculum, which involves revisiting material over time to reinforce concepts, was introduced into the first freshmen engineering course though several means. This notion of using a spiral curriculum is part of an NSF Departmental Level Reform which was awarded to both the Departments of Engineering Education and Biological Systems Engineering (BSE). The twentieth century psychologist, Jerome Bruner, proposed the concept of the spiral curriculum in his classic work, "The Process of Education".[12] Spirals were used on two levels: (1) within the course and the freshmen year (2) with the intention of continuing the spiral for those students who decide to pursue a degree in BSE. Assignments were specifically chosen to create linkages throughout the course. For example, regarding spirals within the course, in one lesson, students were asked to find the surface area of a hexagonal pool noodle by hand. Then, in a separate lesson, students used CAD software, Autodesk Inventor, to find the surface area of the same shape. In another instance illustrating a spiral within the first year of engineering, students were asked to reverse engineer a lawnmower engine during the fall; in a follow-up engineering course to be offered in spring 2005, students will use Inventor to create drawings of parts of the same engine.

Spirals that will exist to the Biological Systems Engineering curricula include engineering ethics. This semester, freshmen students were exposed to the National Institute for Engineering Ethics' Gilbane Gold, a video of a fictitious scenario which raises ethical issues such as contamination of wastewater and the effects of such contamination on agricultural products. Students who enter the BSE will continue to study ethical issues related to bioprocesses by researching and discussing case studies. Likewise, the element of design will continue as a thread between the freshmen and upperclassmen years. While students worked on small scale design projects lasting a few to several weeks during the fall semester, many students will work on a semester-long design-build project in one of the follow-up spring courses. In the BSE track, students have the opportunity to work on more complex design-build projects and a capstone senior design project.

Electronic portfolio

Electronic portfolios were added to the curriculum as a tool to enhance student learning through reflection. The Virginia Tech Electronic Portfolio system (VTeP), available to all students at the university, is based on software from the Open Source Portfolio Initiative. As part of their semester grade EngE1024 students were required to enter specific information and assignments into their ePortfolio and to create a presentation within their portfolio to share with their instructor. The instructor evaluated the presentation twice during the semester, for both content (having the required elements) and quality (of the material included). The assignments included in the ePortfolio were 1) the Learning Styles Assessment mentioned previously including a paragraph in which the student summarized the results and reflected on what he personally could do to enhance his own learning, 2) an ABET reflection paper in which the student interpreted the criteria and examined what it means to be an engineer in light of the criteria and summarized what he expected to learn in courses during the semester that would help him develop abilities in the areas emphasized in the criteria, and 3) an end of semester assignment which consisted on two reflection exercises. In the first of the end of semester reflection exercises the student was directed to revisit the ABET reflection from earlier in the semester and to discuss how he/she would address comments from the grader in future assignments. The second end of semester reflection exercise focused on the three group projects the students had completed over the course of the term. In this reflection the student addressed three issues: how the projects provided evidence of growth towards meeting the outcomes suggested by the ABET a-k criteria, what the student learned about himself as a team member through the projects, and what the student learned about himself as a learner through the projects. Finally, although the student was not required to actually include materials related to one of the projects in the portfolio, the student was asked to identify which of the three projects he would include and why.

The reflective exercises and the ePortolio support both the spiral curriculum and enhanced student learning. Reflection encourages the student to look for connections among the various elements of his education. The ePortfolio provides a repository for storing artifacts which can be used in the reflective process. This electronic storage is an asset to both the student and a reviewer of the materials. Additional information regarding the use of ePortfolio in the COE at Virginia Tech is presented in a companion paper.[13]

Course management

Nineteen faculty members and four graduate students were involved in the creation and/or teaching of the course. Instructors came from a range of academic backgrounds, including Civil Engineering, Mechanical Engineering, Aerospace Engineering, Chemical Engineering, Civil Engineering, Biomedical Engineering, Industrial Systems & Engineering, Engineering Science and Mechanics, Metallurgical Engineering, and Electrical Engineering. A coordinating team of four persons were responsible for generating common exams, developing lesson slides and assignments, creating and implementing research/assessment instruments, managing the faculty members and teaching assistants, and , maintaining a common website for student use. The common website contained common course documents, lessons, assignments, and announcements.

Use of a common website for this fall course was unprecedented; many faculty expressed opinions that they felt the common website saved them a substantial amount of time and effort. However, because faculty members did not post any of the assignments themselves, some faculty members felt that they were less aware of what was occurring beyond the classroom. Many faculty who had taught the previous version of this course felt that they spent the same amount of time preparing for and implementing the new course on a per section basis. While they felt the advising issues and common website saved them time, grading of the increased essay assignments was more difficult and required more time. Also, preparation time for the new course was greater due to the use of Alice; none of the faculty members had prior experience with Alice.

With an unprecedented number of faculty who had never taught any EngE courses previously, a week of intensive training was given to new faculty members. Training included meetings regarding teaching philosophy and style, information regarding the course syllabus and departmental policies, a hands on workshop using Alice, and a hands on workshop to illustrate use of the university's faculty computer accounts and Blackboard (www.blackboard.com). Throughout the semester, the course coordinators led weekly meetings to discuss upcoming lessons and course related issues such as exams, review sessions, assignment of final course grades, etc. Workshops regarding course software, i.e. Inventor, were held on an as need basis.

The backgrounds of the graduate teaching assistants were one of the reasons for the success of the course. Two teaching assistants were from the Department of Teaching and Learning, one was from Civil Engineering, and another was from Computer Science. Duties were assigned to each of the graduate teaching assistants based on their strengths. For example, one teaching assistant had been a high school educational technology teacher, and he has excellent experience in developing hands on activities. Under supervision of the course coordinators, graduate teaching assistant duties included setting up hands-on activities, preparing documents for programming and hands on projects, creating student surveys, compiling homework solutions, and holding office hours. For the Alice portion of the semester, the graduate teaching assistants prepared lesson slides, demonstrated lessons to faculty in weekly faculty meetings, created homework documents and accompanying solutions, generated test questions related to programming, and managed a team of undergraduate teaching assistants.

Future work

A more detailed analysis will be performed on the data collected during the fall. In addition, subsequent engineering courses with programming aspects will conduct additional studies to determine the impact of Alice on programming in C++ and Matlab. Long-term studies will be conducted to look at retention of engineering students and the overall impact to CS students.

In spring 2005, Lo and Lohani will teach EngE1024 again, but in a different format. Instead of two fifty minute lectures each week, the spring course will consist of one weekly 50 minute lecture led by a faculty member followed by a separate 110 minute lab period led by a graduate teaching assistant. Potential advantages to the new format may include reduced teaching and grading time for research faculty and opportunities for students to do more involved in-class activities during the new extended lab period. Furthermore, it will provide teaching opportunities to graduate students. Lo and Lohani will explore ways to grade efficiently, manage graduate teaching assistants who will be teaching lab sections and assisting in the development of the course, and introduce a research-related component and contemporary issues into the course.

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