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Preparing Engineers for an Interconnected World
-The Freshman Year-

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Abstract

This paper discusses how one academic institution is transforming its engineering and technology curriculum to better prepare students for a changing world. Changes in the engineering workplace require engineers to have skills that will enable them to work in virtual environments caused by the globalization of enterprises. To help address this educational challenge, we designed and implemented a pilot freshman engineering and technology course as a first step towards preparing engineering students for global distributed collaborative environments. The design, implementation and the assessment results of the pilot course are discussed in this paper.

I. Introduction

Old Dominion University, Norfolk, Virginia, has a mission to become the premier international university of the Commonwealth of Virginia[1]. In an effort to consolidate and expand the University's emerging reputation as a globally focused institution, the university continues to build and refine its internationally oriented curriculum across all of its colleges; and, through strategic partnerships it provides opportunities to serve the global interests of the community, region, Commonwealth, and nation. The College of Engineering and Technology has embraced the University's mission and has taken the initiative to transform its curriculum to better prepare students to become successful engineers and technologists in any global and multicultural environment.

During the past five years, the effects of globalization on the practice of engineering and technology have dramatically changed. Increasingly, the teamwork and the tools of engineering are moving to the Internet[2]. The importance of co-location and physical proximity of partners and team members has diminished in relation to the importance of connectivity and bandwidth. Through the use of advanced communication and information technologies, engineers and other project team members are now functioning in an interconnected world. They can collaborate in virtual environments that transcend time and space. To be effective in these virtual, or advanced engineering environments, engineers and

technologists must possess specific skills and knowledge that are necessary to operate in these new environments.

A recent pair of studies funded by NASA and issued by the National Academy of Engineering and the National Research Council [3,4] leaves little doubt that the future of the practice of engineering has dramatically changed as a result of past and projected future advances in the creation of advanced engineering environments. These studies also point out the requirement for educational institutions to change their curricula so that graduates can be more effective engineers. Similarly, when analyzing freshman engineering curriculum studies and assessment metrics, there is a clear mandate for change towards e-engineering curricular attributes. ABET EC 2000[5] criteria lists several requirements that graduates must demonstrate, including the abilities to function on multi-disciplinary teams and communicate effectively. Similarly, the Boyer Commission Report[6], reporting on the findings of a study conducted by the State University of New York (SUNY) at Brockport, recommended several actions for improving undergraduate education among which are:

- Every freshman experience needs to include opportunities for learning through collaborative efforts, such as joint projects and mutual critiques of oral and written work
- The freshman program should be carefully constructed as an integrated, interdisciplinary, inquiry-based experience
- Remove barriers to interdisciplinary education
- Link communication skills and coursework, and
- Use information technology creatively

Clearly, the application of collaborative approaches and methods, which emphasize communication skills, multi-disciplinary teaming dynamics, interdisciplinary knowledge application, and use of new technologies in creative fashion, are steps fully in accord with these recommendations. The College of Engineering and Technology at Old Dominion University has started the transformation of the engineering and technology curricula from engineering to e-engineering.

We define e-engineering as "Distributed collaboration in cyberspace using leading edge technologies enabling physically-dispersed, diverse teams to create integrated, innovative and competitive products, systems, and services." Although similar to the definition of Advanced Engineering Environments (AEE) and retaining its fundamental meaning, we emphasize that e-engineering is the practice of engineering in an AEE. Based on the National Academy of Engineering and National Research Council study[4], Table 1 lists the major components and the characteristics of an AEE.

II. The Curricular Transformation

Colleges of business are facing a similar challenge which we believe will face colleges of engineering. They have been actively debating on how to prepare their students for e-commerce. Our objective is for every graduate to have the skills, knowledge, and experience as an e-engineer and be ready to practice engineering within an Advanced Engineering Environment.

Table 1. [4] AEE System Components and Characteristics

Computation, Modeling, and Software
- multi-disciplinary analysis and optimization
- interoperability of tools, data, and models
- systems analysis and synthesis
- collaborative distributed systems
- software structures that can be easily reconfigured
- deterministic and stochastic simulation methods

Human-Centered Computing
- adaptive human-machine interfaces
- networked virtual environments
- immersive systems
- telepresence
- intelligent augmentation

Hardware and Networks
- ultrafast computing systems
- large high-speed storage devices
- high-speed and intelligent networks

We believe that e-engineers should be effective users of AEE's regardless of their discipline, but not necessarily designers or builders of these environments. Hence, the key questions in designing the e-engineering curriculum are: 1) What and how much, if any, of each of the topics in Table 1 should be in the curricula? ; 2) When, where, and how do we introduce the selected materials in each curriculum?; and, 3) What do we take out, or how do we modify existing syllabi so that they meet accreditation guidelines and do not significantly increase the number of credit hours required? These are complex questions worthy of significant faculty debate and consideration that have been initiated, but not completed, at our institution. However, we have taken a significant step in moving toward an e-engineering paradigm in our freshman course, ENG 110-Fundamentals of Engineering and Technology. This course is the first of a required two semester two credit hour per semester course for all freshmen. It is similar to the freshman design course that has been adopted in many engineering curricula across the country.

During the summer of 2000, a faculty task force was appointed to develop a model for a course with an emphasis on distributed collaborative environments using a real-world multidisciplinary product design project[7]. The Intelligent Synthesis Environments Group at NASA Langley Research Center in Hampton, Virginia provided a design challenge and agreed to partner with us in this activity. Simultaneously, students taking a graduate course in Collaborative Virtual Environments were tasked to help develop the conceptual model for the course.

III. Course Conceptual Model

A pilot freshman course was developed and implemented to provide students with the necessary skills in virtual collaborative methodologies and technologies, and application of the methodologies to a real-world multidisciplinary project. The course was taught by three instructors from mechanical engineering, engineering technology and engineering management programs with the following objectives:

1) introduce students to project management, collaborative engineering concepts and methodologies,
2) introduce students to e-engineering communication and information technologies,
3) cultivate team-oriented problem solving approach in a virtual collaborative environment,
4) provide experience for design of products in a virtual environment using 3D modeling and visualization, as well as planning, scheduling, control and implementation of a virtual product development project,
5) provide experience in constructing product prototypes, and
6) provide an understanding for the potential applications and limitations of current virtual product development tools.

The course was offered as a 2 credit-4 hour laboratory course using tools and facilities available at Old Dominion University. As part of an extensive distance learning capability, the University and the College use various distributed course delivery and communications tools with functionality including asynchronous message board, synchronous chat, whiteboard, shared applications, and other communications via audio, video, and e-mail. The laboratory used in support of the course made use of this existing technology infrastructure, including the following capabilities:

- Asynchronous communication in the form of e-mail
- Synchronous communications that include chat, whiteboard and application sharing capabilities, enhanced by audio
- Applications to serve as a user notebook and journal where electronic notes, diagrams, and rafts can be stored for display, sharing, and technical report creation and presentation
- Links or search capability to libraries, on-line journals, and other universities
- Application packages including Microsoft Project for project management, Solidworks for 3D solid design and modeling, Microsoft Excel for analysis, Microsoft Word and Powerpoint for reports and presentations
- ThermoJet machine for rapid prototyping

Prior to the semester, a course web site was constructed with access authorization for the instructors and the registered students. The students were grouped into four teams of six members. For each team, a separate web site was designed for use during project activities. This type of set up allowed the instructors and team members to communicate and share results of collaborative activities. Linked to team web sites, each student designed a personal web page containing essential virtual team information, including contact information, project work availability, and project-related skills.

A real-world project for the course was also identified prior to the course implementation together with Intelligent Synthesis Environment (ISE) Program and International Space Station Program experts at NASA Langley Research Center. In order to simulate a real world environment, NASA experts formed a team to act as the customer during the project. The product challenge for each freshman team was to develop concepts and a rapid prototype of a virtual engineering input device, for use with virtual environment engineering software. The students were responsible for developing innovative and ergonomic hardware components and associated user interface designs to enhance an existing computer input device.

The course can be described in two modules: 1) general module-introduction to project management and virtual collaborative engineering concepts, and 2) specific module-product design and development in virtual environments. This course design is shown in Figure 1. Each module contained general or discipline-specific engineering component phases, which are reconfigurable based on various engineering project scenarios. The course structure is meant to first teach and apply general concepts related to conducting product development in a distributed collaborative team setting. Then, student teams plan and execute specific project tasks while learning and applying multidisciplinary tools and concepts relating to the chosen product development scenario. The following sections describe each module in detail.
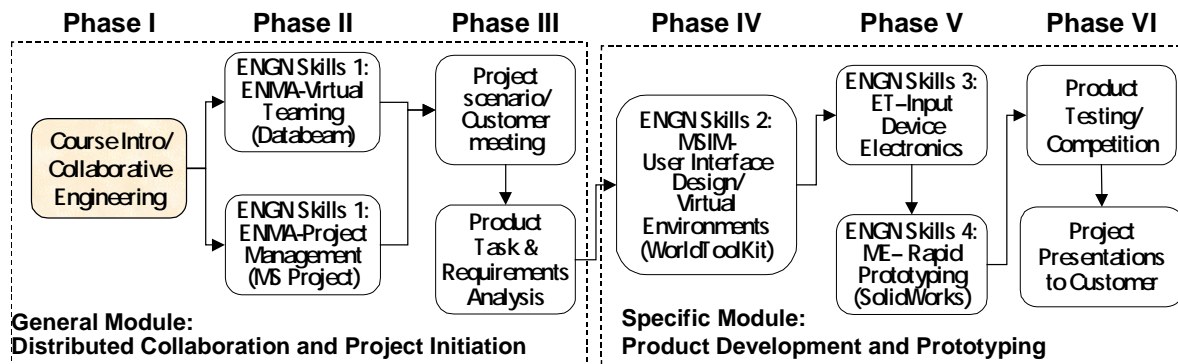
Freshmen Pilot Course Schematic

Figure 1. Course Conceptual Model

IV. General Module – Introduction to Project Management and Virtual Collaborative Engineering

In this module, the students were introduced to fundamentals of project management and collaborative engineering. In Phase I, the course framework was introduced and the 24 students were randomly divided into four teams. These teams stayed together for the entire course, although team leadership and roles changed between course phases. During Phase II, an overview was provided in project management, collaborative engineering, and simple team

building exercises to break the ice for students. Microsoft Project software tool basics were taught to students by hands on practice, homework exercises, and a take home quiz. Basic concepts concerning virtual teaming guidelines were covered, including developing team norms concerning communication and work policies. Databeam and Microsoft Netmeeting collaborative software tool skills were taught, including synchronous audio communication, instant messaging (chat), and application sharing. A web site was established for each team so that project information artifacts, team member web pages, and other project dialog would have a centralized team workspace. During Phase III of this module, the students had a field trip to NASA Langley Research Center to get an overview of the NASA activities and facilities related to virtual collaborative engineering. The NASA customer team also presented input device requirements for a future virtual engineering environment system and demonstrated relevant input device tasks using their current system. This initial customer meeting was videotaped and the video (with key segments highlighted) was distributed on CD-ROM to each team. Teams then applied their collaborative skills with Databeam and Netmeeting to refine each team's statement of work and product requirement definitions using word processing and multimedia applications in a shared environment. By the end of the module, the students were expected to:

- Have an understanding of project teaming, project scheduling, and project management
- Be competent in using MS Project to assist in managing their product development project
- Have an understanding of the attributes of virtual collaborative engineering
- Be competent in computer technologies that are used to design, develop, communicate, and present a collaborative project
- Have a statement of work and requirements definition for the product development project

Throughout the module, the students were assigned individual and team exercises to prepare them for project management and collaboration skills required for the term project. The following is a list of major assignments in the order they are performed during the general module:

- Individuals - Personal web page linked to the team's site
- Individuals - MS Project homework assignments and quiz
- Virtual collaborative teams - MS Project exercise
- Virtual collaborative teams - Develop a refined statement of work for the input device
- Virtual collaborative teams - Develop a list of product requirements for the input device

For the virtual collaboration team assignments, the students shared files, schematics, drawings, and schedules to add or modify while other team members can see and contribute to these documents.

V. Specific Module - Product Design and Development in Virtual Environments

Virtual product development becomes more important with growing application areas and new emerging technologies. This module is designed to provide students with an understanding of virtual product development process by developing and using specific discipline skills relevant to the term project's product requirements. In the case of the initial pilot course's product scenario,

basic discipline concepts and skills concerning human-computer interaction (HCI) user interface design and mechanical engineering rapid prototyping were required.

In Phase IV, basic HCI concepts and techniques concerning task analysis and user interface design were covered. Students were required to demonstrate individual skills in conducting a task decomposition of an input device interactions to prepare for project tasks involving task analysis of NASA's current system. User interface design concepts and a storyboard template technique were explained and each team was required to develop navigation, selection/ manipulation, and mode change mappings to the input functionality of the device. At the end of Phase IV, each team was required to submit an interim project technical report covering team norms, project statement of work and requirements, current system task analysis, and initial concepts for the product's user interface design.

Phase V of the course dealt with developing and applying concepts and skills concerning the rapid prototyping of the exterior hardware components of the device. Concepts and methodologies addressing reverse engineering and rapid prototyping were covered and applied to an existing virtual environment input device. Students learned basic skills of 3D solid modeling using SolidWorks rapid prototyping software and applied these skills to develop enhanced exterior components for the input device. By the end of this module, students were expected to:

- Demonstrate individual skills in conducting a task decomposition of an input device interactions
- Understand and apply user interface design concepts
- Have an understanding of reverse engineering and the rapid prototyping process
- Have an understanding of 3D modeling concepts
- Have knowledge of principles, concepts, and methods for a virtual product development process in a virtual collaborative environment
- Develop a conceptual design, planning, scheduling, control and implementation of a virtual product, which is implemented using virtual collaborative engineering tools
- Have an understanding of how to construct product prototypes
- Have an understanding of how to use prototyping tools, and integrate them into a virtual collaborative environment

The students generated their 3D input device solid design models using SolidWorks. They were required to perform this activity in a virtual environment as teams. Once their designs were completed, each produced a prototype using ThermoJet, a rapid prototyping machine. Similar to the user interface design phase, students were assigned individual and team exercises to prepare them for the skills required for solid modeling and rapid prototyping. The following is a sequential list of major assignments for the specific module:

- Individuals – Perform a task decomposition
- Virtual collaborative teams – Perform a task analysis
- Virtual collaborative teams- Develop a user interface design using storyboard templates
- Virtual collaborative teams -1st Draft of technical report including team charter, project schedule with resource allocations using MS Project, customer requirements, task analysis, user interface design

- Individuals – 3D solid modeling exercise
- Virtual collaborative teams – 3D solid modeling exercise rehearsal of collaborative team skills
- Virtual collaborative teams – Develop an input device hardware prototype concept
- Virtual collaborative teams – Produce a hardware prototype using the ThermoJet machine
- Virtual collaborative teams – Test the prototype using World Toolkit.
- Virtual collaborative teams – Final technical report

The students had a field trip to NASA at the end of the semester to brief the customer team on their final products. The feedback from NASA experts was excellent concerning each team's accomplishments and their creativity in a given short period.

VI.   Assessment and Conclusions

In order to make improvements, the course was evaluated during and at the end of the semester. During the course, informal evaluation was conducted by talking to students and instructors to handle immediate problems. At the end of the semester, two standard teaching evaluations for each instructor were conducted which included a computerized form and a comment sheet. However, the computerized forms do not provide insights on the unique characteristics of the course and its impact on student learning. Therefore, a separate evaluation form was developed and conducted at the end of the course. There were total of 22 questions asked covering all aspects of the course. The students used a scale 1 to 5 where 1-strongly disagree, 2-disagree, 3-somewhat agree, 4-agree, and 5-strongly agree. The results showed that 75% of the students agreed that they developed basic project management and teaming skills; 70% of the students agreed they feel competent on how to use advanced computer technology for virtual collaborative teaming and engineering; 80% of the students agreed that they developed basic skills to work with virtual teams in virtual environments; 75% of the students agreed that the course helped them understand the advantages and implications of virtual teams and technologies; 80% agreed that they learned about engineering design and analysis methods and techniques; 90% of the students agreed that they learned how to use software tools for project management, engineering design, analysis and product prototyping.

The course has been revised to improve upon using results from the special evaluation form, written comments, and the informal student feedback. The order of the course topics has been changed to introduce all skills-related instruction in the general course module. Also, the structure of the course was strengthened by increasing the number and type of individual assignments required for each topical area. Team exercises were also enhanced by increasing the integration between the discipline specific tools, as the teams are required to do in their real-world product development scenario. The enhanced course with modifications is scheduled for the Spring 2001 semester, with a plan to integrate it into the curriculum by Fall 2001.

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