Systems Engineering and Information Technology Education Through the ALIVE System

Paul Stanfield, Jerry Davis
North Carolina A&T State University

Abstract

The environment and expectations facing graduating engineers have changed dramatically in the past decade. Graduate engineers are expected to contribute immediately in competitive environments with system engineering, information technology, and soft skills in addition to traditional engineering fundamentals. The ability of engineering education to produce graduates meeting these market demands will dictate its prominence and viability in the increasingly competitive technical education market. As a result, engineering education needs to develop innovative, portable delivery systems to produce these skills for a diverse and changing student population. This paper describes the prototype development and educational integration of such a delivery system, the NC A&T State Department of Industrial and Systems Engineering "Virtual Enterprise." The Virtual Enterprise (VE) is a full scale manufacturing supply chain, integrated using information technology, and producing an actual product (desk clocks). Departmental laboratories are organized as business departments within the enterprise. The structure and development process for the VE is described. The curriculum integration of the VE is achieved through the ALIVE (Active Learning In the Virtual Enterprise) System. ALIVE is a set of twenty web-based learning modules based on the VE. It provides a practical and consistent means of developing systems engineering and information technology skills in engineering students reaching a variety of learning styles. Three learning module prototypes are described and demonstrated.

1. Background

The nature of engineering practice has changed significantly over the last three decades. The pace of change, driven by increased competitive pressures, has been particularly intense over the last decade. However, engineering education has not changed appreciably over that period. The growing gap between traditional engineering education and the result of many years of change in engineering practice has caused engineering school constituents to question the effectiveness of the programs[1].

1.1 Constituent Needs

Recent literature intended to survey industry needs for engineers produces strikingly similar results. The skills often found lacking in engineering graduates may be divided into three

categories: skills to systemically approach complex design and management problems, skills to appropriately apply information technology tools, and skills needed to function effectively in an organization. A recent survey of engineering practitioners sponsored by the National Science Foundation found that the primary work activity mentioned by engineers was design (66% of respondents included this task) and the tertiary activity was management (49% of respondents included this task)[2]. Engineers have shifted from the traditional role of developer to an integrating role as designer. In cases where corporations have outsourced engineering, the skills needed may be more those of a technical manager than a designer. In either case, workforce changes have created a demand for engineers who can integrate technical, managerial, systems, and financial skills. System design objectives are more complex having to consider a number of strategic, practical, environmental, legal, and time constraints. Engineers need a "breadth of knowledge to handle complex objectives and multidisciplinary functions, to understand non-engineering issues, and to perform systems engineering in a loosely bound environment" [3].

The second most cited activity from the NSF sponsored survey was computing [2]. The impact of the information technology explosion is well-documented and very visible. This explosion has tremendous implication in terms of demand for and responsibilities of engineers. Two organizations that are of primary importance to the practice of Industrial and Systems Engineering have emphasized the importance of information technology [4,5]. Businesses continue to rely on information technology not only to increase individual performance, but as the primary tool for integration to the supply chain or enterprise level. If the primary responsibility of engineers will be systems design and integration, information technology will certainly be the primary tool. The technology used for information systems has consistently outpaced the sophistication and fluency of its implementation. The key to successful information technology implementation is not in the technology itself, but rather in the ability of engineers to manage its implementation As a result, systems engineering and information technology are intricately linked as supporting the success of each other.

The last skill area includes those "soft" skills such as written and oral communication, presentation skills, leadership competence and the ability to work on multidisciplinary teams. These skills support the ability of the engineer to function effectively within the business enterprise. In addition to these national trends, alumni, students, and employers of the NC A&T State University Department of Industrial and Systems Engineering continue to emphasize these skill areas.

1.2 Traditional Engineering Education Methods

Traditional engineering education was developed during a time of heavy government funding of research and development. The research and development function stresses engineering science and theory over engineering practice[1]. The format is the traditional classroom lecture where the instructor is active and the student is passive. Learning is achieved through abstract conceptualization rather than concrete experience. Application is implicitly determined through

reflective observation rather than explicitly determined through active experimentation. The transition from engineering student to engineering practitioner is rapid and disjoint. Few activities resemble engineering practice prior to graduation and few activities resemble engineering theory after graduation. This style of teaching, perhaps sufficient for teaching engineering "fundamentals" is grossly inadequate for teaching systems skills, information technology skills, and soft skills. Furthermore, traditional approaches ignore learning styles of large segments of our population, inhibiting recruiting, retention, and diversity efforts.

The traditional focus tends to reduce problems to a manageable size for application of analytic methods. The problem is isolated from many highly related issues. This decomposition approach is useful for research and development, but inadequate for practice in a complex world. A typical curriculum consists of fairly isolated classes (except for maybe two or three course successions) with little overall integration. Systems thinking considers the impact of related issues. Understanding of such issues is often better experienced or learned through example; it is difficult to articulate and ineffectively taught in a lecture environment. Traditional engineering education minimizes the impact of information technology in terms of teaching and subject matter. Information technology is viewed as too transitory to teach. Engineering design of information systems is not included in many curricula. Faculty members themselves are often underskilled in the application of information technology. Finally, traditional engineering education ignores soft skills as inferior topics. Faculty activities do little to encourage development and use of these skills to improve engineering education.

1.3 Engineering Education Advances

It is unfair to contend that no trends in engineering education have sought to recognize the changing requirements for those in engineering practice. The recognition of the desperate need for change has been a prominent topic in recent engineering education literature. Attempts to consider the systems approach have led to attempts at course integration; and increasing use of information technology has introduced new teaching methods and allowed students access to software used in practice.

Integration is primarily visible in the form of capstone senior design projects common in most engineering schools. Curriculum designers are increasingly more aware of developing courses that combine skills from several prior courses to practice systems design. Especially innovative approaches introduce students to systems thinking early and continuously through their program, stressing both engineering and business issues[6]. Programs that have sought to emphasize this approach have ranged from small-scale graduate programs[7]; to departmental[8]; to large-scale multi-institutional efforts[9]. Successful programs supplement traditional engineering science with practical experience in solving real problems. Though the contributions of these efforts are significant, none really addresses the problem of developing a base model for a holistic engineering curriculum.

Perhaps the most significant demonstration of the changes being expected of engineering education is the revision of the accreditation process, termed ABET EC 2000. Under this accreditation process, engineering programs will be expected to borrow techniques established by engineering practitioners in Total Quality Management (TQM) to develop an assessment process based on outcomes rather than activities. With the extent of existing faculty load and the natural resistance to change, it is questionable whether these changes will yield appreciable educational reform without the development of model curricula. Without proper planning and forethought, changes will be made in a piecemeal manner; lacking any examination of the motivation for change, the factors that have resisted change, or the unintended consequences of the changes being considered[10].

2. Virtual Enterprise

The NC A&T State University Department of Industrial and Systems Engineering Virtual Enterprise (VE) is a full scale manufacturing supply chain, integrated using information technology, and producing actual product. Departmental laboratories are organized as business departments within an information system-integrated enterprise. The VE departments, their function, and conceptual structure can be seen in Figure 1 with the physical structure and equipment shown in Figure 2.
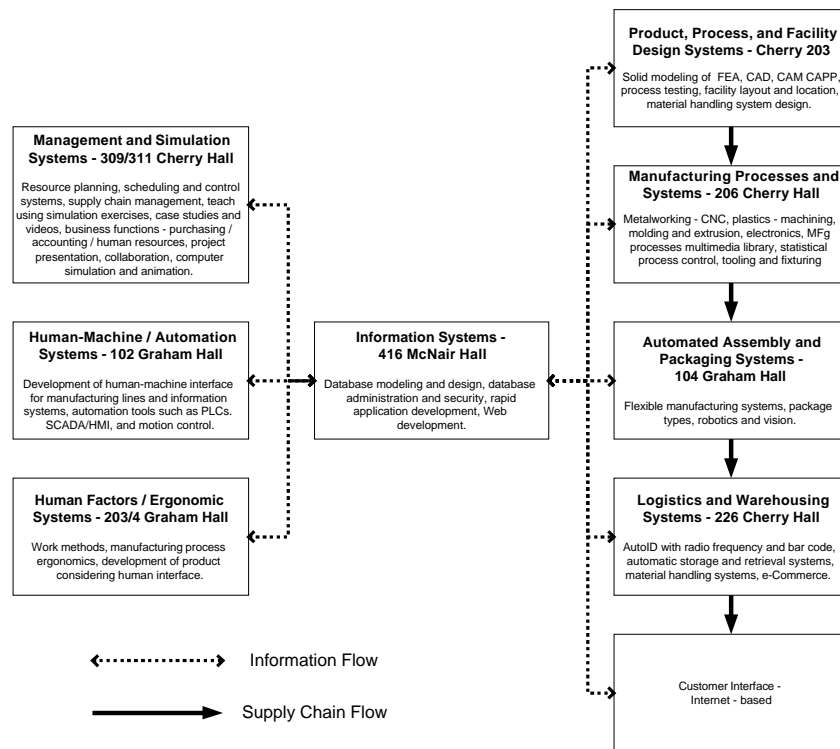

Figure 1: Virtual Enterprise Conceptual Structure

Human-Machine Systems
Graham 102
(1000 sq. ft.)
AB PLCs (6)
HMI TouchScreens
GE Motion control system
Conveyor control system

Data HSNC (6)

Assembly and Packaging Systems
Graham 104
(1150 sq. ft.)
CRS Robot
ASRS Gantry Robot
Adept Robot and vision
AB PLC
EMCO VMC Machine Center
Bridgeport CNC Mill
Flexlink conveyor

Data HSNC (6)

Human Factors / Ergonomics Laboratory
Graham 203/204
(100 sq. ft.)
Ergonomic treadmill
Exercise bike
Methods watches
Performance measuring equipment

Data HSNC (6)

Graham Hall

Information Systems
McNair 416
(400 sq. ft.)
Database administration software
Rapid application development
Web development

Data HSNC (6)

McNair Hall

Product, Process, and Facility Design Systems Cherry 203
(800 sq. ft.)
Feedback SCARA Robot
Rhino Robot Cell
Movemaster Jointed Arm Robot
Solid Modeling Software
Z Corporation 3D Printer
Cognex Vision System
Facility Design Software
CalComp E Plotter

Data HSNC (4)

Manufacturing Processes and Systems Cherry 206
(879 sq. ft.)
CNC Mill
CNC Lathe
Other Metalworking
Plastics - Blow, extrusion, injection molding
CMM / Metrology/ SPC software

Data HSNC (4)

Logistics and Warehousing Systems Cherry 266
(630 sq. ft.)
Intermec bar code system
Sortation Systems
Warehouse model
RF transmitter
Bar code printer
Remote distribution transmitters

Data HSNC (4)

Management and Simulation Systems Cherry 309/311
(720 sq. ft.)

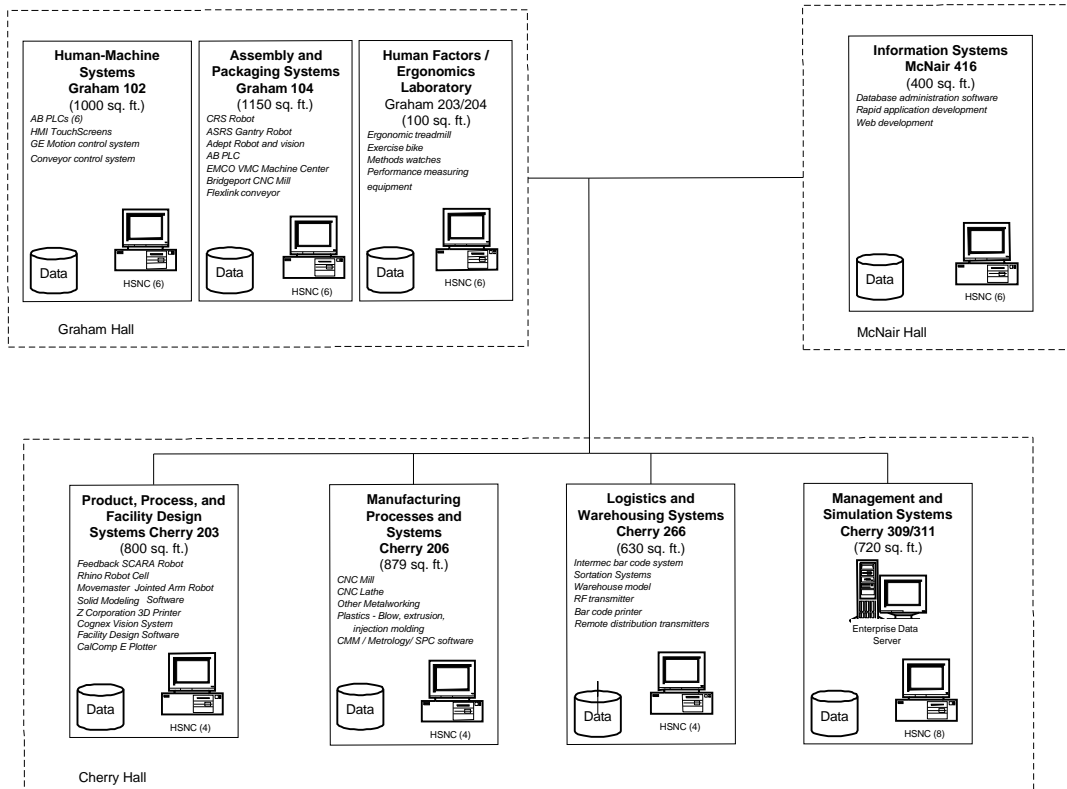Enterprise Data Server

Data HSNC (8)

Cherry Hall

Figure 2: Virtual Enterprise Physical Structure

2.1 VE Development

VE systems development requires completion of the following steps undertaken by the Department of Industrial and Systems Engineering with assistance from the National Science Foundation and Procter and Gamble. Steps 1-5 are complete. Step 6 is in progress.

1. *Infrastructure Development* – All departments (laboratories) are equipped with at least two performance computers with connection to a common high speed network.
2. *Process and Equipment* – Processes necessary to design, manufacture, and distribute the desired products are identified. Small scale, flexible manufacturing equipment with computer interface is purchased to perform these processes (in our case, much of our existing equipment is used).
3. *System Integration* – Purchased equipment are connected to the VE system infrastructure. In our case, all equipment is accessible over an Ethernet network with TCP/IP protocol or through computer connecter to Ethernet network.
4. *Database Design* – The enterprise data model is developed. The data model is comprehensive and complete to be realistic, yet straightforward and simple to promote learning. Our data model contains about 70 entities. The data model has portions associated

with supply, product, engineering, manufacturing, distribution, sales and marketing, finance and accounting, human resources, information systems, and other entities. The model is implemented in Microsoft SQL Server.

5. *Server Construction* – The infrastructure is connected to database and Web servers. The database is a client-server relational DBMS. The Web server is used for asynchronous student learning and Web-enabled applications and has a secure interface to the database computer. The Web server has been developed to allow both ASP and JSP functionality.

6. *Program Development* – Simple programs to perform specific departmental functions are written to have the same "look and feel" and demonstrate realistic operation of the department. Programs are based on documented process models using data flow diagram structure.

2.2 VE Products

The VE system is designed with flexible processes to handle multiple products. The initial VE product is a desk clock as shown in the Figure 3 assembly (without timepiece). The desk clock is designed using parametric solid modeling and with a rapid prototyping system in the Product, Process, and Facility (Engineering) Department. Parts are manufactured using injection molding and CNC machining and inspected using a CMM in the Manufacturing Processes and Systems Department. Automated assembly is accomplished in a flexible assembly cell. The cell possesses CNC capability to custom engrave initials and vision-guided robot insertion to insert a timepiece with the correct time (according to the time zone of the customer). The assembly process allows teaching of production postponement and delayed differentiation concepts. A second planned product is a disposable camera. This product facilitates teaching of reverse logistics, product recovery, and remanufacturing.
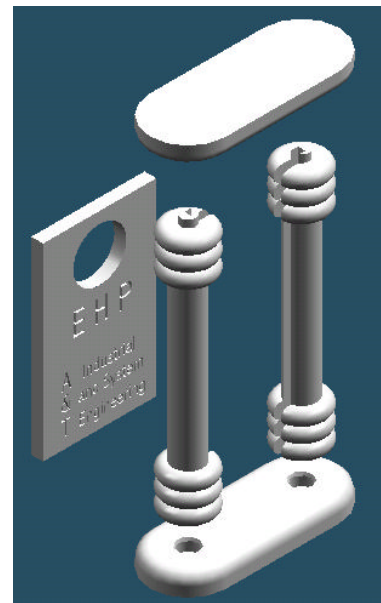

Figure 3: VE Clock

3. ALIVE System

Curriculum integration of the VE is achieved through the ALIVE (Active Learning In the Virtual Enterprise) System. ALIVE is a set of twenty web-based "learning modules" based on the VE (see Table 1). The ALIVE system provides the equivalent of many short intern experiences in many functional departments of the same small company. It provides a practical and consistent means of developing systems engineering, information technology, and business skills in engineering students. The pedagogical design reaches a variety of learning styles. Learning module structure and initial prototypes of the three initial learning modules are described below.

3.1 Learning Modules

Each student learning interaction with the virtual enterprise is termed a learning module. Each undergraduate course will have at one or two learning module(s). Learning modules are performed in teams and typically will consume one week of class time each. A learning module requires successful completion of the following steps:

1. Learning objectives – The module starts with a listing of module learning objectives, the basis for student evaluation. The objectives are written using Bloom's Taxonomy to encourage higher leveling thinking. The learning objectives also contain an emphasis on developing problem solving skills in students.
2. Functional training – The next step is to have the student team perform the laboratory exercise focusing on the related functional area. This step is where most laboratory experiences begin and end, with the student left to make all inductive conclusions.
3. Data / process model – The student team will review and analyze the data and process models associated with integrating. The student will learn how to use the virtual system interface. The Web interface allows the student to navigate through the data model and see entity and attribute definitions and types. The process model interface allows decomposition to the code level. (Students will learn how to understand data and process models early in the curriculum.)
4. Economic / value issues – The business issues involved in this function are described with student teams producing a tradeoff analysis.
5. Other design issues – The student team is introduced to additional systems issues including (where appropriate) social, safety, ergonomic, global, political, and regulatory concerns.
6. Individual evaluation – Each student is evaluated to ensure learning in steps 2 and 3 above. This evaluation is done by a test of skills learned in step 2 and the ability to write appropriate database queries for step 3.
7. Case study – Finally the team demonstrates the ability to synthesize all information learned from steps 2-5 by performing a case study. In the case study, each team member will take on a different role (production manager, engineer, accountant) to assist in collaborative learning. The case study encourages problem solving and higher level thinking skills.

Instruction regarding the learning modules is implemented in Web-based format to enhance portability and enable asynchronous learning.

The overall curriculum has been modified to enhance the student experience by having three IT courses in the first two years, three seminar classes teaching soft skills, and a systems engineering course in the senior year to enhance the capstone design project. With the addition of disposable cameras, learning modules focusing on design for recovery, reverse logistics, scheduling under uncertainty, and disassembly will be constructed.

Table 1: Initial Learning Module List

Module Title	Labs	Classes	Class Title
Industrial Engineering Programming	416 McNair Hall	GEEN 102	Computer Programming for IE
Introduction to Virtual Enterprise	All	INEN 246	Manufacturing Processes
Custom Manufacturing	206 Cherry Hall	INEN 246	Manufacturing Processes
Computerized Performance Tracking	102 Graham Hall	INEN 255	Methods Engineering
Activity vs Standard Product Cost	311 Cherry Hall	INEN 260	Engineering Cost Management
Enterprise Data Modeling	416 McNair Hall	INEN 280	Information Technology
Enterprise Web Database Interface	416 McNair Hall	INEN 280	Information Technology
Team Decision Making Using IT	311 Cherry Hall	INEN 289	Engineering and Teams
Statistical Process and System Control	206 Cherry Hall	INEN 325	Quality Control
Inventory Level Optimization	226 Graham Hall	INEN 330	Operations Research I
Manufacturing Execution	104 Graham Hall	INEN 346	Automation and Production Systems
Process Reengineering/ Improvement	104 Graham Hall	INEN 346	Automation and Production Systems
Production Scheduling and Control	104 Graham Hall	INEN 355	Production Control
Distribution Planning and Tracking	226 Cherry Hall	INEN 355	Production Control
Material Handling and Control	203 Cherry Hall	INEN 365	Facility Layout / Material Handling
Enterprise Operator Interface	102 Graham Hall	INEN 370	Ergonomics
Virtual Enterprise Simulation	311 Cherry Hall	INEN 415	Simulation
Product Redesign / BOM Maintenance	203 Cherry Hall	INEN 424	CAD/CAM
Process Planning and Tracking	203 Cherry Hall	INEN 424	CAD/CAM
Virtual Enterprise Business Functions	311 Cherry Hall	INEN 485	Systems Integration

3.2 Learning Module Prototypes

The first learning module "Introduction to the ALIVE system", teaches students the process of completing a learning module. The functional portion of the learning module consists of a tour of the departments (which can be done virtually as well as physically). The data and process model teach web navigation using the browser. The economic and environmental issues facing the company, named Aggie Industries are reviewed, and an initial case study looking at product improvement is performed.

The second learning module, "Manufacturing Processes", allows the students to make each part needed for the clock (other than the timepiece which is purchased externally). The laboratory includes mill, lathe, and injection molding operations; demonstrating CNC machining and computerized operator assistance. The case study addresses a decision where to make the clock scrolls using injection molding or machining.

The third learning module, "Manufacturing Execution Systems", demonstrates the execution of a production schedule generated by a planning system on an automated assembly and packaging system. A daily production schedule is downloaded and the MES communicates with the assembly and packaging cell to produce the required product. The case study investigates the cost and effort required to implement an MES.

3.3 ALIVE System Implementation

Effective implementation of the ALIVE system faces several challenges, the initial one being the technical issues of equipment, process, and IT integration. Even after successful physical integration, curriculum integration presents several challenges. The first challenge is securing faculty acceptance and participation. All faculty have been involved in the decision process to change the nature of our laboratories. To further encourage participation, faculty members associated with each undergraduate class will be involved in the development of the learning module substance. Faculty will be trained to: (a) understand the developed modules in the context of the virtual enterprise; (b) develop teaching module substance within the context of the standard delivery mechanism.

In addition to inadequate faculty training, another potential problem in implementation is poor lab preparation for module execution and poor lab maintenance to ensure repeatability. The ALIVE system uses standards for all modules to promote preparation and maintainability. These standards impact both the learning module and delivery mechanism. The maintenance structure defines needed tasks and the roles of faculty, technicians, graduate students and undergraduate students. The standards and the structure are highly interrelated. The Web-based nature of the learning modules also assists in improving accessibility.

The VE / ALIVE System is portable to other academic programs. The IT structure requires campus network computers connected to Web and database servers. The database server should be client server (such as Oracle or SQL Server). The normalized data model for the VE may be quickly created in the database server. If the academic program desires to perform all physical laboratories, then the capability to perform CNC milling and machining, small scale injection molding, and automated inspection is required. A current VE equipment list is available. If equipment purchase is not feasible, the academic program may use Web-based streaming videos of the equipment function as part of the learning modules. It is anticipated that some learning modules will be use by business school students using the alive.ncat.edu Website.

3.4 ALIVE System Evaluation

The effectiveness of the ALIVE approach to engineering education will be assessed with respect to the project objectives. The objectives and associated measures are listed below:
1) Attracting students to engineering
   a) Increase in number of freshman students opting for Industrial Engineering due to ALIVE exposure
   b) Increase in number of students who transfer into the Industrial Engineering program due to the ALIVE
   c) Retention rates of students in the program attributable to the virtual enterprise

2) Preparing engineers for the workforce
   a) Employer feedback on graduate preparedness to practice engineering
   b) Alumni feedback on their ability to practice as engineers
   c) Faculty evaluation of students' system integration ability based on capstone design project
3) Acceptance by faculty
   a) Percentage of department faculty using a one or more course modules
   b) Percentage of course modules incorporated into the curriculum
   c) Faculty feedback on usefulness of the teaching modules
4) Dissemination to other programs
   a) Number of other programs that receive curriculum notes or teaching modules
   b) Number of visitors to web site

Surveys and other feedback instruments are developed and administered to a representative sample of each target population. Positive trends in the measures should attest to the value of the proposed approach. The project will also be evaluated through a longitudinal study of a randomly selected cohort. The cohort will be tracked over five years to gain insight into the achievement of the above objectives.

4. Conclusions

The ALIVE system is based on proven educational techniques. Effective pedagogy in engineering education is based on teamwork and cooperative learning, interdisciplinary nature of problems, active participation in learning, open-ended projects that allow communication among students, computers treated as a means and not an end, and knowledge content and its application being interrelated. The virtual enterprise supports each of these notions of effective pedagogy. Each learning module allows the student to learn through experience in a "real world" environment. Learning modules are developed around explicit instructional objectives to encourage higher level learning. Students learn collaboratively. Each learning module is designed to better reach active, reflective, global, visual, and inductive learning styles. The proposed project is different from traditional engineering education and from disjoint attempts to address needed changes through class content changes and integrating design classes. ALIVE should meet its goal of systems engineering, information technology, and soft skill development. In addition, the ALIVE system helps students better understand the interrelationships between courses, enhances student recruiting and retention, and enables a smoother transition to the profession upon graduation. The developed results can be easily shared with others to yield a high leverage result. As a result, the goals for the ALIVE system is to attract higher numbers and more diverse students to industrial engineering, to promote an enhanced educational experience, and to result in a greater level of career success and satisfaction.

References

1. Lang, J.D., Cruse, S., McVey, F.D., and McMasters, J., "Industry Expectations of New Engineers: A Survey to Assist Curriculum Designers," *Journal of Engineering Education*, January 1999.
2. Burton, L., Parker, L., and LeBold, W.K., "US Engineering Career Trends," *ASEE Prism*, May-June 1998.
3. Morgan, R.P., Reid, P.P, and Wulf, W.A., "The Changing Nature of Engineering" *ASEE Prism,* May-Hune 1998.
4. Engineering Criteria 2000, Criteria for Accrediting Engineeering Programs: Effective for Evaluations during the 1999-2000 Accreditation Cycle: Engineering Accreditation Commission. Accreditation Board for Engineering and Technology; http://www.abet.org/download.htm, 30th November 1999.
5. Curricula 2002; Manufacturing Education for the 21st Century; Volume I: David L. Wells, Editor, Society of Manufacturing Engineers, 1995.
6. Panitz, Beth, "The Integrated Curriculum," *ASEE Prism*, September 1997.
7. Cherrington, B., "An Integrated Approach to Graduate Education in Manufacturing Systems--The U.T. Dallas Model", *Journal of Engineering Education*, January 1993.
8. Pardue, M.D., "Architecture for a Successful Computer-Integrated Manufacturing Program in a 4-year College or University", *Journal of Engineering Education*, Janruary 1993.
9. Lamancusa, J.S., Jorgensen,J.E., and Zayas-Castro, J.L., "The Learning Factory— A New Approach to Integrating Design and Manufacturing into the Engineering Curriculum", *Journal of Engineering Education*, April 1997.
10. Goldberg, D., "Change in Engineering Education: One Myth, Two Scenarios, and Three Foci", *Journal of Engineering Education*, April 1996.

PAUL STANFIELD
Paul Stanfield is an Assistant Professor of Industrial and Systems Engineering at North Carolina A&T State University. He is a registered Professional Engineer and a member of INFORMS and IIE. Dr. Stanfield received a B.S. in Electrical Engineering, M.S. in Industrial Engineering/Operations Research and Ph.D. in Industrial Engineering from NC State and an M.B.A. from UNC-Greensboro.

JERRY DAVIS
Jerry Davis is a graduate student in the Department of Industrial and Systems Engineering at North Carolina A&T State University. Jerry received his B.S. in Industrial Engineering from North Carolina A&T State University and is a member of IIE.