Teaching Innovative Product Development Skills to Freshmen Engineering Students

J. Mark Barker and David Hall
Mechanical Engineering Program
College of Engineering and Science
Louisiana Tech University

Introduction

A new course of instruction has been developed and delivered on a pilot basis at Louisiana Tech University. The goal of this course sequence is to provide freshman engineering students selected tools essential to innovative product development and to provide them the opportunity to use these skills in a product development project.

The development of this course of instruction was motivated by several factors. One is the relatively new emphasis at Louisiana Tech University on entrepreneurship. This emphasis has a central focal point on campus, the Center for Entrepreneurship and Information Technology, or CEnIT. The mission of this center is to create an innovative entrepreneurial culture at Louisiana Tech University. In order to change a culture, it is reasonable to begin with new members of that culture. Another factor is the authors' desire to see an improvement in the senior design projects for the capstone mechanical engineering design course sequence. These projects could benefit by attempting to have a marketable product as a final result. A third factor is the belief that entrepreneurship begins by having ideas about a product, and survives by being able to do something with the idea, and that ability can be taught. Entrepreneurial courses have been offered at Tech, typically to upperclassmen. The goal of this project is to effect these changes by providing freshman engineering students with experience in product development.

The resulting course is a significant modification to an existing freshman engineering course sequence. The development, delivery, and results of this course are the subject of this paper.

The Original Courses

The freshman engineering curriculum at Louisiana Tech University, which is on the quarter system, includes a three-course engineering sequence. These courses are labeled ENGR 120, 121, and 122, Engineering Problem Solving I, II, and III. The primary purpose of these courses is to provide early engineering experience to accompany the math and science courses. These courses aid the students in determining proper academic major selection. The content of these courses includes an introduction to selected engineering topics closely related to or integrated with the content of the math and science courses.[1] These topics include elementary problem solving, statistics, electrical circuits, material balance, mechanics of materials, and 3D modeling. The students also gain experience using software tools such as Excel, MathCAD, and Solid Edge related to these topics. In these engineering courses, the students do most of their work in teams, including homework problems, laboratory activities, and presentations. The year culminates in a design competition between the ENGR 122 teams. For example, a recent competition was to design and construct a device that will climb a rope while carrying a weight in a specified time.

The Modified Courses

Funding and approval for the modification and delivery of a single section of the freshman engineering course sequence was obtained during the Fall quarter. Rather than wait a year, we decided to begin with ENGR 121 in the Winter quarter, and continue with ENGR 122 in the Spring quarter. This limited course development time, but a foundation of topics and skills related to product development appropriate for freshman was identified. From this foundation, the daily class outlines were developed a few class meetings in advance. This approach allowed easy modifications based on the results from previous class meetings, while avoiding a one-year wait. A plan was formulated to introduce these topics and skills to the students in a way that would prepare them for a final project in the product development process. It was anticipated that starting in ENGR 121 would have some benefits, as the course population would consist of students who had successfully completed their first term, including ENGR 120 and the beginning mathematics and chemistry courses.

The major objective of this project was to develop and deliver a course sequence that prepares freshmen engineering students for and gives them experience in innovative product development. This paper details the course development, delivery, and the results of the student product development projects.

The product development process includes generating a product idea, brainstorming the product, formalizing the product through sketching or modeling, manufacturing a prototype, testing and evaluating the prototype, refining the product design as a result of prototype evaluation, and repeating the prototype fabrication and evaluation process to further refine the product design. Traditional engineering analysis is not present in this process, primarily due to the lack of training for these freshman students. It is hoped that this experience will provide personal motivation for the study of the engineering fundamentals in their academic future.

In order to prepare the students for the product development process, important skills were identified and incorporated into the course plan. These include idea generation or brainstorming, 3D modeling, fabrication, microprocessor programming, and engineering and data analysis skills. The following paragraphs will describe the importance of each to innovative product development.

In order to take an idea or concept from the brain to the market, it is important to be able to communicate to others what it looks like and to identify important physical parameters such as size and shape. Often this occurs on the back of a napkin; however, the ability to generate a three-dimensional model of an object is important for innovative product development, particularly for interfacing with rapid prototyping machines. Solid Edge, a 3D modeling software application, was selected to provide this capability. The students were instructed in the use of this tool, were required to model various objects using this tool, and their individual proficiency in using this tool was measured.

A key feature of many newly developed products and improved existing products is the ability to sense their surroundings and respond to their surroundings. These can be considered "smart" products. The sensing and response capability is typically accomplished using embedded microprocessors. The microprocessor receives input from sensors, interprets these inputs with programmed logic, and controls a device. A simple example is a thermostat, which measures temperature and turns on the furnace or air conditioner when the temperature is outside the comfort zone. Many devices such as this have been mechanical or electro-mechanical in the past, but are being replaced by electronic devices. In order to provide experience in this critical product development area, an educational microprocessor kit was selected. This kit, which resembles a robotic vehicle, is a Boe-Bot by Parallax. This robot kit includes a Basic Stamp II microcontroller, a chassis and servo-powered wheels for travel, and a breadboard for adding various sensors and actuators to the system. This kit was selected for the variety of sensors available, the amount of educationally-oriented literature available, and the expected appeal of working with a robot. Figure 1 shows an assembled Boe-Bot kit.[2]

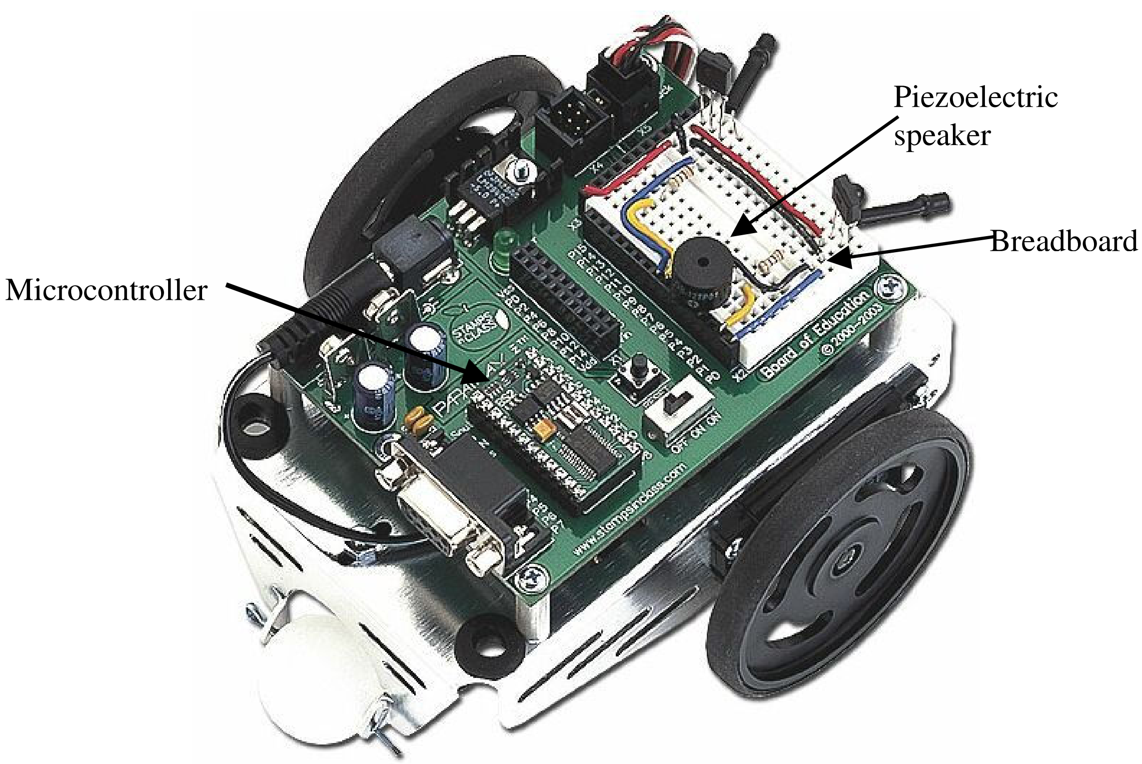

Figure 1. Assembled Boe-Bot kit.

In order to classify the product development process as innovative, an innovative plan or philosophy of product development is required. The product development philosophy of IDEO is chronicled in the book by Kelley.[3] This philosophy formed the basis for the approach to product development in this course. Briefly stated, their philosophy is to have an open exchange of ideas and to develop products through prototyping early in the process. These prototypes are used to evaluate a design and to refine the design, leading to additional prototypes and refinements in a timely manner. A video recording of a network news program which documents the IDEO product development process is available.[4] This video was viewed in class and served as an instructional tool regarding the process, and as an inspirational tool, resulting in student enthusiasm for their product development tasks.

Prototype construction and evaluation requires both fabrication skills and analysis or evaluation skills. This is a crucial element in the innovative product development process. Early prototype construction can be from simple materials such as cardboard and duct tape. As the prototype is refined, the construction should be refined as well, as the prototype approaches a functional product. For this course, selected fabrication skills were identified to be appropriate for freshmen engineering students and prototype construction. Instruction and experience in these skills was provided through instructor demonstrations and student hands-on activities. These included cutting metal with a saw, drilling and tapping holes, cutting threads, and bending metal using a brake. Electrical connection fabrication skills such as wire stripping, soldering, crimping, and heat shrink protection were also included.

In order to test and evaluate prototypes, engineering and data analysis skills are important. These students had experience with statistics from ENGR 120, including normal distribution and linear regression. Data analysis was emphasized throughout this course, with the students expected to present data graphically and to determine functional relationships from the data. This emphasis included significant experience with both MathCAD and Excel to present the data and determine these relationships. Engineering or system analysis was discussed in example form, particularly as it related to the performance or behavior of their developing product designs.

These modified versions of ENGR 121 and 122 also included content from the original courses, including electrical circuits, material balance, and mechanics of materials. The engineering fundamentals of electrical circuits were quite useful in understanding the circuits required for the electrical components such as capacitors, resistors, and LEDs included in the Boe-Bot kit.

These skills would provide the students with experience in generating ideas, the ability to develop solid models of their ideas, an understanding of how “smart” products function, and a platform to configure their own “smart” products. The students would also have the ability to fabricate prototypes, evaluate them, and refine their product design based on these evaluations. These skills provide the basis for these students to do their own innovative product design as required for the final project for this course sequence.

Course Details and Equipment

In this section, selected details of the course content and the equipment used in the course will be described.

An important feature of the original courses is to introduce students to the engineering disciplines. This is typically done through student research and presentations, or through guests who are practicing professionals in engineering. Similarly, the engineering fundamentals are selected to provide problem solving experience that can be identified with the various engineering disciplines. In the modified course, this content was preserved by selecting experiments and activities related to the innovative product development skills and identifying these by specific engineering discipline. Table 1 below identifies the engineering discipline and the associated experiment or activity from this course related to the discipline.

Table 1. Engineering discipline and related activity.

Engineering Discipline	Experiment/Activity
Civil Engineering	Traffic study experiment / Follow the leader robot activity
Chemical Engineering	Flow control activity with liquid level indicator and controlled pump
Mechanical Engineering	Torque and power measurement to determine ideal motor operation

To provide background for the traffic study experiment, a civil engineering professor with experience in transportation spoke to the class and described a typical traffic study. The students were required to locate and read a recent article on automated highways. The students then gathered data on the response times of drivers stopped at a stoplight-controlled intersection. These data were analyzed to determine the appropriate statistics (average, standard deviation) of the response times. Each student then programmed their robot vehicle to follow the vehicle in front of it a certain time after that vehicle moved. The students were assigned various reaction times based on the response time statistics. This follow the leader activity was used to measure the vehicle throughput rate. To investigate the affect of automation, the robot vehicles were then programmed to follow with a reduced uniform response time. The measured vehicle throughput increased, and the automated vehicles were able to maintain safe distances. The students were required to write a paper relating these experimental results to automated highways.

A major emphasis of this course is to gain experience with a microcontroller. This included gaining experience with a variety of sensors. The students learned about the sensors, such as the physical phenomena relevant to the measurement, and learned to acquire data from these sensors. The students also learned to program the Boe-Bot to respond to the data acquired from these sensors. For example, an infrared transmitter/receiver pair can be used to detect objects. The students programmed the Boe-Bot to recognize the sensor output as an object in their path and programmed the Boe-Bot to avoid the object.

These sensors were typically introduced and demonstrated by the instructor in class, and the students then incorporated these sensors and performed different tasks as classroom activities and homework assignments. Later in the course, the students were assigned a project to identify a new sensor and introduce it to the class through description and demonstration. This would allow the students personal experience in adapting new sensors and widen the class perspective on available sensors. It was anticipated that ideas for how to use these sensors in a product would result. The list of sensors used in the class in these ways is extensive, as shown in Table 2 below along with a typical application for the sensor.

Table 2. Sensors and typical application.

Sensors	Application
Whiskers	Object detection using physical contact
Infrared Transmitter/Receiver pair	Object detection using electromagnetic wave
Photoresistor	Determine light intensity
Capacitance	Determine presence of liquid
Accelerometer	Measure angle of inclination
Infrared Transmitter/Receiver pair	Information exchange between autonomous robots
Infrared Transmitter/Receiver pair	External robot control using infrared remote
Radio Frequency Transmitter/Receiver pair	Information exchange between robots
Ultrasonic rangefinder	Distance estimation; object detection
Compass	Travel direction
Color Identification Camera	Identify object color

It is important for a "smart" device to respond to the environment it senses by performing some action. The Boe-Bot vehicle has the ability to respond to sensor input in several ways as used in this course. The simplest response is to use a piezoelectric speaker to emit a sound based on the value of the sensor input. The typical Boe-Bot configuration includes a speaker on its breadboard, and the microcontroller can control the frequency and duration of the sound. Another response is for the Boe-Bot to move. The Boe-Bot has independently driven wheels, allowing it to move forward, backward, or to turn. More sophisticated control is also possible by combining these movements. External devices can be controlled. For example, a transistor can be used as a switch to control an external device. In the chemical engineering experiment a liquid level detector was used as a sensor, and the microcontroller used a transistor to turn a small liquid pump on or off. Information from the microcontroller can be displayed using the Boe-Bot computer interface or an LCD display can be connected to the breadboard.

The Course Delivery

For this pilot delivery of the modified course sequence, we had the luxury of two instructors in the class. This allowed us to evaluate the course content and the students' interpretation of it in real time. The course content was delivered to maximize the integration of the engineering skills with solving real world problems and, after building a sufficient set of skills, to relate these skills to innovative product development.

Innovative Product Design Project

As the skills were developed through classroom instruction and experience, along with new sensors and capabilities, the instructors guided the students in discussions. These discussions dealt with how to incorporate these into a larger system (a product) to perform a useful task. In small groups, then as a class, the students brainstormed product ideas that could result from our sensor and actuator capabilities. Although they were not informed, this activity was designed to assist with idea generation for the major project assignment.

The project assignment was to develop a product of their choosing by developing the product concept, building a series of prototypes, and presenting these prototypes to the class informally to promote discussion about the product. The student projects were required to include the Basic Stamp controller and the Board of Education platform, which is the interface between the sensors and actuators and the Basic Stamp controller.

The students were expected to generate their own ideas independently or from limited instructor input. The instructors suggested a broad category of products, identified as Blind Assistance Devices. This seemed appropriate as both Louisiana Tech University and the Louisiana Center for the Blind are located in Ruston, Louisiana. Also, the university houses the Professional Development and Research Institute on Blindness, commonly referred to as the Institute on Blindness, a cooperative effort between the University and the Louisiana Center for the Blind.

Table 3 shows the project schedule. A memo communicating the product idea for each group, including sketches, was required from each group. This was followed by a series of prototypes. The prototypes were presented informally to the class and were discussed by the class. The instructors and students provided valuable feedback useful for refining the product concept. The prototype quality expectations increased for each prototype. The final prototype was a functional prototype and was demonstrated in class. Later, each group made a formal presentation identifying the steps taken in their innovative design process.

Table 3. Innovative Product Design Project schedule.

Date	Event
Thursday, April 3, 2003	Project Assigned
Tuesday, April 8, 2003	Product Concept (memo and sketches)
Thursday, April 10, 2003	Prototype #1
Thursday, April 24, 2003	Prototype #2
Tuesday, May 13, 2003	Final Prototype
Tuesday, May 20, 2003	Final Project Presentations

This project schedule is important for two reasons. Product development with prototypes early and often in the process is a cornerstone of the IDEO process or philosophy and is the primary reason for multiple prototypes in the project schedule. A secondary reason is to provide students with project milestones that must be continually met to ensure that they keep working steadily on the project.

The Results

The modified course sequence was advertised to students enrolled in ENGR 120 prior to advance registration for the Winter quarter. The resulting population of 23 students for the ENGR 121 course was the result of self-selection and the ability to successfully complete online registration. The innovative product development projects were contained in the final portion of the ENGR 122 course in the Spring quarter. At this time, the class consisted of 17 students, and they formed groups of 2-3 students, resulting in 8 groups. We will refer to these groups by group number, and will identify group member gender and academic major. This group information is provided in Table 4.

Table 4. Group description.

Group Number	Number of Students, Gender, and Engineering Discipline Major
1	2: F, Basic; F, Biomedical
2	3: M, Chemical; M, Basic; M, Biomedical
3	2: M, Civil; M, Biomedical
4	2: F, Biomedical; M, Biomedical
5	2: M, Electrical; M, Mechanical
6	2: M, Industrial; M, Civil
7	2: M, Mechanical; M, Civil
8	2: F, Basic; M, Basic

Table 5 identifies the project for each group. Rather than describe each project, selected comments will be made about the projects.

Table 5. Group project.

Group Number	Project
1	Musical relaxation fountain
2	Blind person assistance device
3	Currency identification device
4	Seeing-eye robot
5	Infrared glove remote control unit
6	Powered hydration unit
7	Intelligent cane for the blind
8	Automatic flag device

It is evident that several of the groups developed products based on the instructors' suggestion. Group 3 and 7 expended considerable effort in researching their product. These groups made several contacts with personnel and people served by the Louisiana Center for the Blind to research the special needs of blind people. Groups 2 and 4 then followed suit once this was mentioned in the informal prototype presentations. These groups incorporated various sensors into their projects. For example, Group 7 added features to a typical cane for the blind. They added an infrared sensor to detect objects above the waist of a blind person that the cane would not typically detect. After finding from their research that a blind person's hearing is crucial to their mobility, they developed a device that would cause the cane to vibrate when an object was detected. This group considered patenting their device and took their device to the National Federation for the Blind convention this past summer. The other groups mentioned included other object detection sensors as well as location sensors such as compasses. Group 3 incorporated a color detection camera into its currency identification device. Figure 2 shows a photograph of their final prototype.

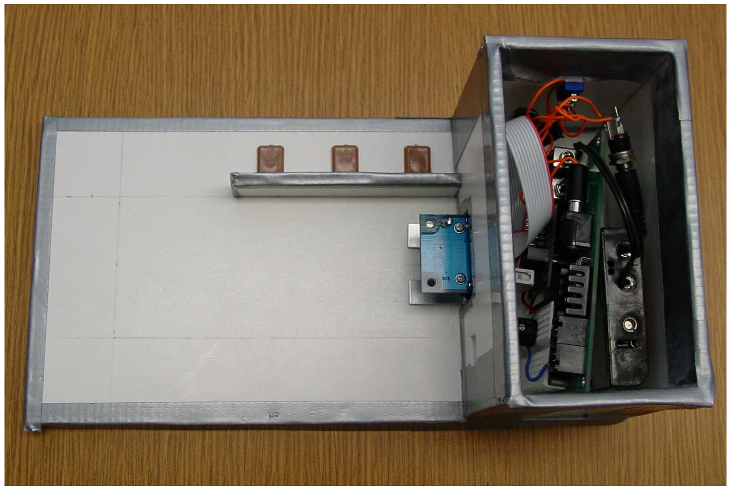

Figure 2. Final prototype of currency identification device.

Group 5 developed an innovative product for the common task of channel surfing. The remote control glove seen in Figure 3 incorporates an infrared transmitter and touch sensors in the fingers. By touching different fingers together, selected infrared signals are generated that can be used to control devices such as televisions and DVD players.

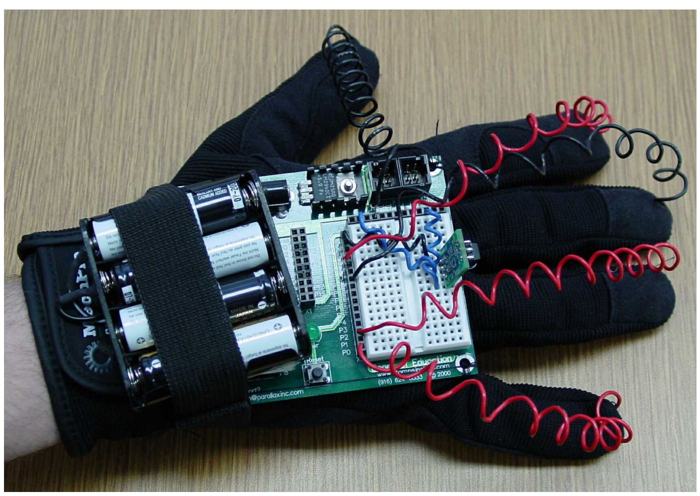

Figure 3. Final prototype of infrared glove remote control unit

Summary

The skills deemed appropriate for innovative product development were mastered by the students, which can be shown in the results of significant individual assessments. The students were enthusiastic about using their skills to develop products, aided in part by the video documentary of the IDEO design process. In some cases, this enthusiasm waned over the course of the project. In other cases, the student groups maintained a high level of motivation and interest in the development of their product design. In all cases, the student groups met the project requirements. There were some difficulties with system reliability, particularly in those products that incorporated multiple sensors and actuators. The difficulties also seemed to be related to the level of time commitment.

In several cases, the quality and usefulness of the student products was much greater than anticipated. It is difficult to determine the success of this course. The previous judgments are quite subjective. It remains to be seen whether these students will perform better in their engineering courses due to motivation from this course. Will the culture at Louisiana Tech University begin to change towards innovation and entrepreneurship? Will these students produce exceptional products in their later design courses due to this innovative product design experience? These questions will not be answered for some time. However, a significant amount of positive feedback was received from those involved and those who observed, and this course sequence is being offered again in the 2003-2004 academic year.

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Biography

J. MARK BARKER is an Assistant Professor in the Mechanical Engineering Program at Louisiana Tech University. He holds a B.S. degree in Mechanical Engineering from Louisiana Tech University. He earned his M.S. and Ph. D. degrees in Mechanical Engineering from Clemson University. He typically teaches courses in the thermal fluid sciences, experimental techniques, and the freshman engineering curriculum.

DAVID HALL is an Associate Professor in the Mechanical Engineering Program at Louisiana Tech University. He holds a B.S. degree in Mechanical Engineering from Louisiana Tech University. He earned his M.S. and Ph. D. degrees in Mechanical Engineering from Georgia Tech. He typically teaches courses in mechanics and materials, CAD, and the freshman engineering curriculum.

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