AC 2007-710: A CLASS FOR UNDERGRADUATE TECHNICAL LITERACY USING LEGO MINDSTORMS

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Abstract

Much effort is underway to encourage students to pursue careers in science, technology, engineering, and mathematics. There is a growing base of infusing these necessary skills and attitudes to stimulate the pursuit of these avenues as careers. There is also much effort aimed at addressing the diminishing skills in math and many of the sciences. As technology is becoming pervasive in many US classrooms, the skills and knowledge necessary to utilize this technology is being provided to students. However, there is little effort to build a broad base of understanding and appreciation of engineering principles that lies behind much of our technology today. This paper presents a class which was developed to provide an exciting, hands-on method to explore engineering concepts using LEGO MINDSTORMS. The class was targeted toward those students who would not normally choose an engineering or technology profession. These participants learned about engineering in a practical and useful manner using LEGO Robots. This paper will present the class, the modules developed for the class and the results of the workshop held in August 2006. The desired outcome of the class is that technologically non-proficient citizens will be better prepared to function in a global, technology-intense world.

Introduction/ Motivation

"Are we providing students with the intellectual skills and background they will need to appreciate and continue learning about SME&T [Science, Mathematics, Engineering and Technology] throughout their lives?"[1]. There is a growing need to build a broad base of understanding and appreciation of engineering principles that lies behind much of our technology today. These skills need to be established in those students who would never take an engineering class. The new liberal education must include technology as a key component.

Much has been made of building business understanding, communication skills, and the ability to work in teams into engineering undergraduates. At a conference of industry leaders, one CEO stated that he wanted engineers with business knowledge. But, he also wanted business graduates to have a basic grasp of engineering principles. Van der Vink[3] stated that we need our politicians and business managers to consider engineering concepts in their decision making process, "…Our long-term future depends on citizens understanding and appreciating the role of science in our society."

Wichita, Kansas has a great need for technologically skilled workers with an understanding of the engineering process. Wichita is home to multiple aircraft companies such as Boeing, Raytheon Aircraft, Cessna, and Bombardier, in addition to non aircraft companies like The Coleman Company, Koch Industries and Vulcan Chemicals. WSU has a growing need to bridge engineering principals into the undergraduate general education program for all students. This course was the first attempt at exposing all undergraduate students to engineering concepts. A course, engineering 101, has been previously offered for many years and is still offered each semester. Engineering 101 serves two purposes: 1) To prepare engineering freshman to succeed in college and 2) to expose them to the different engineering disciplines. However, this course does not target the familiarization of non-engineering undergraduates to engineering concepts. WSU's Colleges of Business, Health Professions, and Education graduate many future leaders that could benefit from hands-on experience and knowledge of the engineering process that they will spend their careers supervising.

Our country glamorizes lawyers and doctors on television, yet engineers are viewed somewhat with wonder and contempt. The closest media icon for engineers is, "Dilbert." While humorous to most engineers, the icon likely does not improve our image. If undergraduate students were exposed to basic engineering principles early in their degrees, more would appreciate the effort involved in the design and manufacture of a product. There is a strong need to expose undergraduate students to engineering concepts to enable a stronger, more engineering literate workforce among non-engineers. "We must do this for all students, both those who do and those who do not aspire to be scientists, mathematicians, and engineers"[2]. According to Wulf, "[Every citizen] should also be familiar with the methods that engineers use to evaluate design alternatives in search of the one that best satisfies constraints related to cost, functionality, safety, reliability, manufacturability, ergonomics, and environmental impact" [3].

In summary, we need to improve the technological literacy of our non-scientific workforce. A course that exposes non-engineering undergraduates to engineering concepts is essential to improve the technological literacy of our country. The remainder of the paper describes an implementation of this type of class.

Method

LEGO and LEGO MINDSTORMS have been used by many to teach engineering concepts. Turbak and Berg[4] have developed a "Robotic Design Studio," to introduce Engineering to Liberal Arts Students. Nickels and Giolma[5], use LEGO MINDSTORMS to teach non-engineers about science and technology. Several use MINDSTORMS to teach engineering to engineering freshmen and to integrate engineers of different disciplines[6,7,8,9]. Garcia and Patterson-McNeill[10] use MINDSTORMS to teach software development. LEGO is conducive to a constructionist[11] approach to learning. This approach has been used extensively in computer-based education. This approach works well to perform experiments that are time-consuming, as the process can be "sped-up" to allow multiple observations. However, learning is greatly improved with "hands-on" activities. LEGO MINDSTORMS provides an excellent tool to combine both computer-based education and hands-on learning[12].

This effort was part of an adaptation and implementation grant and therefore had three main sources of material for adaptation. The first was two texts: one written by Dr. Wang[13] which contains exercises demonstrating engineering concepts; the other text was an introductory LEGO MINDSTORMS text written by Mario Ferrari[14]. The course also incorporated some of the training methods using the multimedia curriculum created by Robin Shoop[15]. This curriculum contains activities and worksheets tied to STEM content standards with corresponding assessment rubrics. The primary adaptation and implementation component, as well as key to dissemination was the ROBOLAB[16,17] software written by Dr. Rogers, which was used to introduce students to programming.

The following section describes the development of the course.

The first task was the development of the engineering modules. A team of engineering faculty, along with an educational strategies specialist from the college of education, developed modules presenting basic engineering content in a manner understandable to all undergraduate students. Modules were developed for each engineering discipline represented at Wichita State University: aerospace, computer, electrical, industrial, manufacturing, and mechanical engineering. A module was also developed covering the engineering design process. The adaptation of existing modules from various sources was used to achieve the pedagogical objectives. For example, at the end of one module students will be able to describe the use of gears and how gear ratios can increase torque and the environments in which increased torque would be beneficial.

The second task was to develop the actual course. The WSU project team and the collaborators planned to teach the course in the Summer of 2005. Example learning objectives for the course are:

- articulate the engineering design process,
- build a simple gear box using LEGO MINDSTORMS and describe the rationale of "gearing up and gearing down,"
- demonstrate different methods to propel a vehicle,
- draw a completed MINDSTORMS assignment using engineering drawing principles,
- explain why engineers draw their designs and how it aids in analysis,
- demonstrate the different types of sensors,
- describe how these sensors work,
- apply the sensors to a design problem,
- program a MINDSTORMS device using ROBOLAB, and
- articulate how the design of the manufacturing system can affect the feasibility of a product.

A key factor for the course to be successful was for the course to have no pre-requisites. The minimal pre-knowledge requirement was intended to ensure maximum participation among those who might be hesitant to enroll in an engineering course. A key aspect of the course is the presentation of student designs to their peers and industry panels. However, all presentations and grading will be on a merit criteria of the engineering product and the student's ability to communicate that design to a diverse audience. This is also a vital component for women and minority participation. A course outline and learning objectives are shown in Table 1.

Table 1. Course Outline

- General programming:
    - Define the different parts of a Robolab program (Programming I)
    - Program in all Pilot levels (Programming I)
    - Demonstrate a program and execute it on the RCX (Programming I)
- Computer Drafting:
    - Explain the difference in drafting views (CAD)

  - Design instructions to be followed by fellow students (CAD)
  - Properly list a Bill of Materials (CAD)
- Aerospace:
  - Identify the major components of the airplane and what they do (Flight controls)
  - Label the pitch, roll and yaw motions of an airplane (Flight controls)
  - Identify the control surfaces of an airplane and the motion they control (Flight controls)
  - Takeoff and fly an airplane in a flight simulator (Flight controls)
- Mechanical Engineering:
  - Explain how rotational motion is converted to translational motion and vice versa. (Gears)
  - Name and explain the function of the main components of a gear train. (Gears)
  - Build a simple gear train to specifications of the ratio of input to output speed, torque and/or power. (Gears)
  - Read simple electric circuits diagrams. (Sensors)
  - Explain the operation of selected transducers. (Sensors)
  - Design, build and program MINDSTORMS projects using a variety of transducers. (Sensors)
- Electrical Engineering:
  - Identify various digital storage devices. (ISAT)
  - Describe major features of various storage devices. (ISAT)
  - Indicate what storage devices are used in the Robolab system, and where. (ISAT)
  - Identify various means of electronic transmission of data. (ISAT)
  - Describe major features of various transmission methods. (ISAT)
  - Indicate what transmission methods are used in the Robolab system, and where.
- Industrial Engineering
  - Explain the difference in production systems (compare/contrast push and pull)
  - Define WIP
  - Demonstrate the impact of inventory to flexibility and cash flow

The third task was to disseminate the class in a workshop. WSU hosted the Midwest Robolab Workshop with collaborators in August 2006. The class was presented along with similar efforts at other institutions. In order to increase attendance and participation at the conference, there were two tracks. The first track was: "Undergraduate Education" and the second track was "K12 Education." Chris Rogers was the keynote speaker as he is the author of the ROBOLAB programming language for LEGO MINDSTORMS. In the undergraduate education track, the speakers were: Keith Levien (Chemical Engineering applications) and Don Wilcher (Industrial Applications). In the K12 track the speakers included both national and regional K12 experts using ROBOLAB. Both tracks had several workshops that attendees from both track participated in. Attendees from around the country participated in the workshop.

Module Design

Each module was designed as an independent unit of instruction. The lesson plan for each module included: title, objective, connection to SCANS (skills, reading, math, science objectives), the essential concepts, vocabulary words and terms, background information and knowledge base, real-world connection, activity, materials, and assessment. The modules were: Introduction (to class and LEGO MINDSTORMS), Gearing Principles, Flight Controls, Engineering Graphics, Information Transmission and Storage, Sensors, and Production Systems.

Each of these modules used a consistent format. Day 1 (scheduled for 2 hours) had a lecture and some basic hands-on. Day 2 (scheduled for 2 hours) was mostly all hands-on. Each of the four faculty involved were assigned a module to develop and teach. Additional activities were planned for many classes (video presentations, demonstrations, etc.). The course was scheduled so one module was taught, then a break to complete the lab – for example a Wednesday or weekend with no class), then the next module was taught.

Four of the modules had a lab assignment as well. A project report template was available to the groups. The template had the following sections: Abstract, Objective, Introduction, Background/Theory, Method/Procedure, Equipment, Results, Discussion of Results, Reflection and Future Applications. The rubric is shown in Appendix A. The first lab assignment was simply to design and construct a line following robot. The primary purpose of this assignment was for the student groups to become comfortable with the project report format and rubric. The second lab was concerning gearing. This lab required the students to build a stepper motor clock (instructions were provided) as shown in figure 1. The first lab (called lab 2a) was then modified to include the engineering drawing (building instructions) requiring the group to develop a digital model of their line follower design. The third lab was concerning Information Transmission and Storage. For lab three, the students were to build a binary to digital converter. The student groups first built a breadboard device which output the numbers in binary format using LEDs. Then, the students built a device in LEGO bricks to sense the output and write a program in ROBOLAB to convert it to decimal. The converter is shown in figure 2. Additional assignments were to build a flight simulator (shown in figure 3) and to participate in a LEGO Airplane factory demonstration (shown in figure 4).

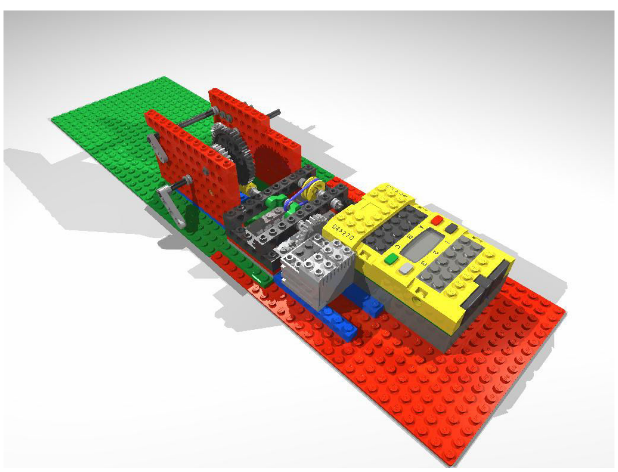

Figure 1. Stepper Motor

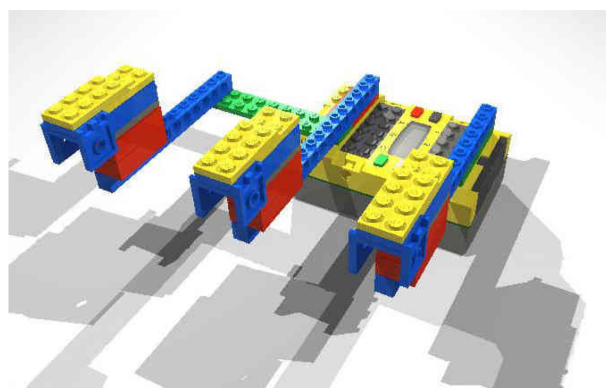

Figure 2. Binary Converter

Each of the modules had a specific objective and building instructions were provided. Students had to build the module and develop the program. For some of the labs, building instructions were simple and some of the programming was simple. But, all of the modules required the students to demonstrate that learning was achieved. Figure 5 shows the potential complexity of a program as shown by the flight controls software. The final class shows students the importance of process design in industrial engineering. Table 2 shows typical results from a sample class exhibiting the importance of cash flow and inventory policy. The students built the planes in different production methods (phases) and differences in policy made the the difference in the profit or loss for the line.

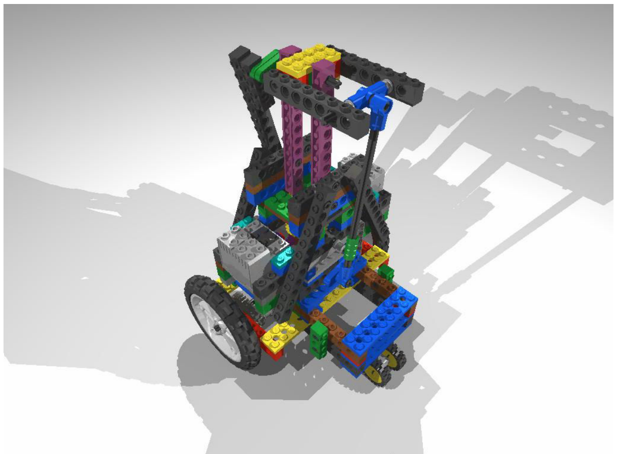

Figure 3. Flight Simulator

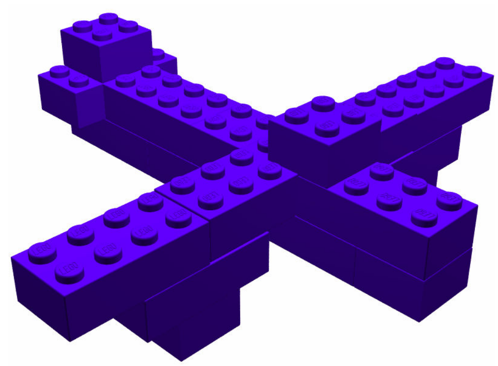

Figure 4. Airplane Production

Table 2. Typical Airplane Production System Results

	Max Good Planes	Min Good Planes	Min Time 1st Good Plane	Max Rework	Max Scrap	Max WIP	Max Profit/	Max Loss
Phase-I	5	0	5:15	5	14	29	3000	-10400
Phase-II	5	0	4:40	5	17	50	0	-13000
Phase-III	17	13	0:46	2	3	5	32000	0
Phase-IV	25	21	1:00	0	3	5	48800	0

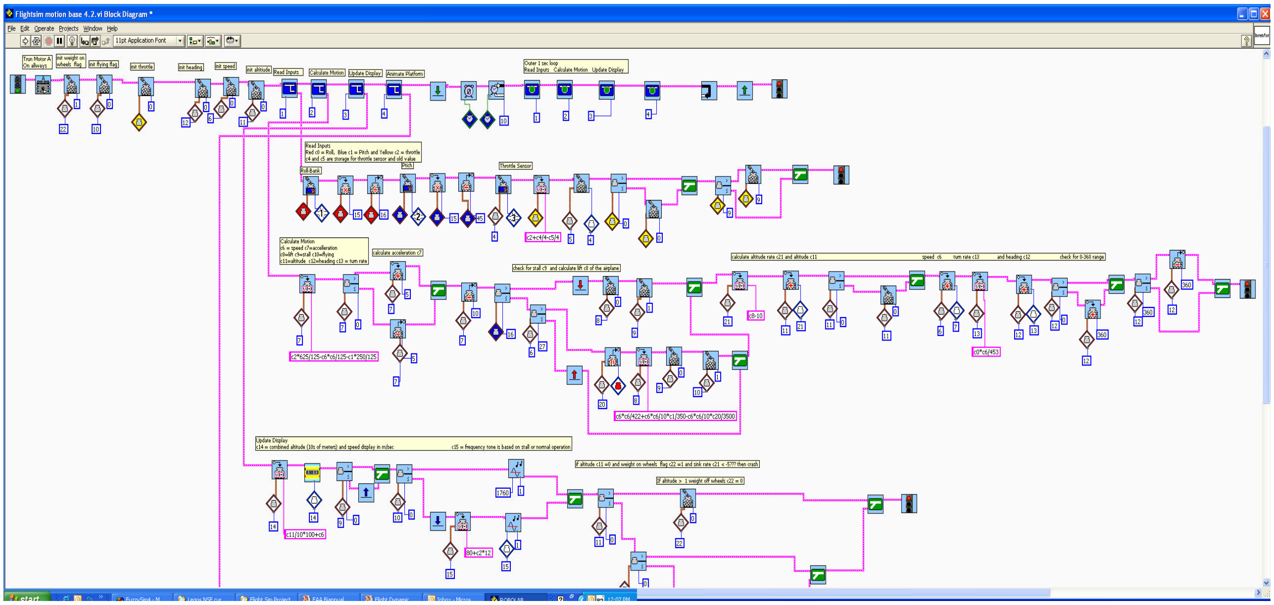

Figure 5. Robolab Program for Flight Simulator

Conclusions and Future Directions

The class was received well by students and faculty. Students rated the class well and liked the variety of faculty and variety of topics. Faculty liked to see the students learning the basics of their subject matter. The modules are posted on the web at http://www.wichita.edu/techlit.

One of the key difficulties of this class was enrollment. The original intent was to have the class counted as part of the “general education” requirements. Due to university policies this is not currently possible. Students are not to willing to enroll in a class without receiving credit toward their degrees.

Another difficulty with this class is the engineering material presented. The engineering disciplines presented in this class were tailored to the disciplines offered at Wichita State. Other engineering disciplines such as Chemical Engineering and Civil Engineering were not included. Preliminary attempts to develop a Civil Engineering module using a truss bridge with LEGO Technic have been promising. Chemical Engineering modules were demonstrated by Keith Levien at the Robolab workshop held last August.

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Project Assessment Rubric

Format, Style, and Appearance	1 Poor	2 Developing	3 Adequate	4 Exemplary	Pts	Comments
Professional Appearance	Report is typed; some graphics are hand drawn; and/or 1-5 mechanical errors	Report is typed; graphics are computer generated; 1-5 mechanical errors	Report is typed; graphics are computer generated; absence of mechanical errors	All of the previous and an acceptable electronic copy is submitted		
Graphical Communication	The report contains only text.	The report contains text and only one other method of communicating.	The report contains several methods of communicating information (i.e. diagrams, drawings, photos, tables, charts, graphs, written information, etc.). One or more items either don't clearly add value, are not accurate, or are not correctly labeled and captioned.	The report contains several methods of communicating information (i.e. diagrams, drawings, photos, tables, charts, graphs, written information, etc.). Each item clearly adds value and accurate information to the report. Each item is correctly labeled and captioned.		
Organization and Style	The information appears to be disorganized. Paragraphing structure was not clear and sentences were not typically related within the paragraphs.	Information is organized, but paragraphs are not well-constructed. Paragraphs included related information but were typically not constructed well.	Information is organized with well-constructed paragraphs. Most paragraphs include introductory sentence, explanations or details, concluding sentence, and transition.	Information is very organized with well-constructed paragraphs and subheadings. All paragraphs include introductory sentence, explanations or details, concluding sentence and transitions well to the next paragraph.		
Page Limit	8 or more pages	7 pages	6 pages	5 pages or less (body of report) not including Title and Table of Contents		
Title Page	Format incorrect	Format correct	Format correct and contains all group member names	Format correct, contains all group member names, group number, and roles are varied		

				from last report		
Drawings	Hand Sketched	MLCAD drawings of most parts	MLCAD drawings including complete parts list	MLCAD drawing showing individual steps to allow reproducibility		
Innovation	Absent	Got the basic idea right	Design showed beginnings of a new approach	One of the most innovative ideas in class		
Skills used	No clear use of class learnings	Used class techniques	Explicitly used three or more class techniques appropriately	Explicitly used three or more class techniques appropriately and demonstrated the initiative to self-learn by acquiring skills or knowledge beyond coursework		
Accuracy	Many errors in the report	Two minor or one major technical errors	One minor technical error	No technical errors		
Body						
1.0 Abstract	Disorganized	Less than half page summary of the work; unclear objective or no results are presented	Less than half page; useful summary of the work; the objective is clear and accurate; and discussion of results are presented	Less than half page; useful summary of the work; the objective is clear and accurate; and a brief discussion of results/method		
2.0 Objective	The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant.	The purpose of the lab or the question to be answered during the lab is partially identified, and is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is identified, but is stated in a somewhat unclear manner.	The purpose of the lab or the question to be answered during the lab is clearly identified and stated.		
3.0 Introduction	Does not add value	Partial: Present but not clearly articulated and not understood	Present and clearly articulated and mostly understood	Present and clearly articulated and understood		
4.0 Background/Theory	Present, but does not add value	Partial: Present but not clearly articulated and/or weak	Present and clearly articulated and provides a good overview	Present and clearly articulated and understood. Provides a good overview and articulates relevant		

				details.		
5.0 Method/ Procedure	Present, but not logical or appropriate	Logical, but not appropriate	Logical and appropriate	Logical, appropriate, and presents sufficient detail		
6.0 Equipment	Not organized in a useful manner	Present, but not complete	Present and Complete	Present, complete, and special parts are described fully		
7.0 Results	Does not provide multiple solutions	Provides less than 3 possible solutions.	Provides at least three possible solutions	Provides at least three possible solutions, articulating pros and cons for each. Also, presents a useful discussion on the rationale for each alternative.		
8.0 Discussion of Results	Not organized in a useful manner	Rationale for final design is present, but lacking a logical basis	Rationale for final design is logical, but does not accommodate all variables.	Rationale for final design is logical, accommodates all the pertinent variables.		
9.0 Reflections and Future Applications	Absent	Haphazard discussion	Discussion explained some of the results	Clear understanding of principles discussed with content from results		