Lessons with LEGO® - Engaging Students in Chemical Engineering Courses

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"How can we generate more enthusiasm and improve the team skills of our students through incorporating hands-on experiences in chemical engineering based projects?" This is the question we have tried to address at Oregon State University by initiating projects which involve the popular LEGO® building system. This was initially motivated by the realization that the robotics line of these kits could be used for data acquisition, but the concept of using the familiarity of LEGO pieces to enhance engineering design activities was quickly applied in first year courses.

LEGO Products and Education

Most LEGO parts are made of an ABS plastic to very strict tolerances. A broad range of pieces provides the flexibility to easily construct a wide variety of structures. With the TECHNIC® line and (since 1998) the Mindstorms® products, children have been given the opportunity to create and program fairly sophisticated robots.

The DACTA® educational division of LEGO has created additional technology kits for use in school curricula. To support the use of the RCX® programmable microcontroller, Tufts University worked with National Instruments to produce a software environment called ROBOLAB®, based on National Instruments's product LabVIEW®. Over the last four years the FIRST LEGO League (FLL) robotics competition organized for middle school children has grown from 200 to 30,000 students in Europe and the USA - all of whom have gained engineering design and programming skills working on teams. These children will enter universities within a few short years with a solid foundation of computer applications in engineering systems. The educational challenge will be to provide a compelling learning experience for these first-year students as well as for those who have had no opportunity to perform engineering tasks in K-12 classes.

In this paper we propose that the LEGO hardware/software combination is a flexible approach to provide hands-on experiences for undergraduate teams working on projects. Particularly attractive is the relatively low cost and ease of maintenance. An active adult user community for the RCX and Mindstorms® products (which is web-based accessible) ensures that future developments in additional sensors and actuators will occur. A survey article which points out some of these exciting opportunities, "Mindstorms Not Just a Kid's Toy" was written by Paul Wallich and appeared in the September IEEE Spectrum issue. It is available on-line at: www.spectrum.ieee.org/pubs/spectrum/0901/mind.html

Curriculum Implementation: First-year Courses CHE 101 & CHE 102

In the Fall quarter 2001, 45 students enrolled in CHE 101 "Chemical Engineering Orientation". CHE 101 is a 3 cr. course (3 hours of lecture and 2 hrs of laboratory per week), with one lecture hour reserved for guest speakers from industry. The class size ranges from 45 – 55 students, with laboratory sessions limited to 15 students. It is always a challenge in a freshman course to find an open-ended design problem that is challenging, cost effective, and FUN! The answer to this challenge for the CHE 101 class in Fall 2001 was the "LEGO-modified" Chem-E Car Competition (C^3). This was a modified version of the AIChE National Chem-E Car Competition that has been ongoing for several years. The primary modifications to the national competition were:

1) the car construction had to be completed with the LEGO Creator kit, which was supplied to each group of 3 students;

2) the load to carry and distance the car had to travel were given at the outset instead of being variables supplied on RACE DAY;

3) the student groups had only three weeks to design and build their car, select their chemical reaction system, and turn it into a "propulsion" system to move the car. The details and deliverables are shown in the class handouts contained in the APPENDIX.

In the Winter quarter 2002, 47 students enrolled in CHE 102 "Introduction to Chemical Computations" programming course. CHE 102 is a 3 cr. course (1 hour of lecture and 4 hrs of recitation/computer lab per week). Prior to this year the course was based primarily on MATLAB, but this year the students were also introduced to the ROBOLAB graphical programming language for data acquisition using the LEGO RCX microprocessor. Students worked in 2-3 member teams to became familiar with the hardware/software combination. They initially ran some dynamic experiments on the cooling of a heated styrofoam "heater box" using a LEGO motor/fan combination, as shown in Figure 1.

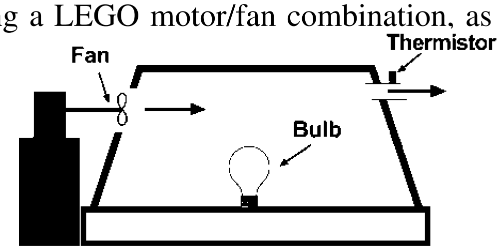

Figure 1

In the 5th week of the quarter, they were given step-by-step instructions to build and to program a simple line-following, basic structure robot. Finally they worked together in a design project which required extensive modifications of the mechanical design of the robot to perform advanced tasks including following a line, data acquisition of distance and temperature as functions of time, and do some simple decision making in response to the three sensor readings.

ABET Criteria 3 Outcomes

We believe the LEGO projects provide us the capability to address several of our departments locally defined ABET Criteria 3 Outcomes (l-q), which are:

l) formal practices of project planning and management
m) the ability to identify what information is missing and to formulate specific critical engineering problems when given complex process problems
n) the ability to make rapid and intelligent engineering decisions with minimal data
o) the ability to find trends in large quantities of process data and relate those trends back to fundamental chemical engineering process principles
p) the ability to identify modifications to process equipment to improve process performance
q) the ability to evaluate multiple process technologies in a broad context, i.e. safety, environment, cost etc.

In support of these, we also introduce first-year students to professional skills development. These skills are developed in depth in the junior and senior laboratory courses in chemical engineering. In particular, the following are considered as part of the "Professional Skills Toolbox":

Team Skills
Conflict Resolution
Effectiveness: Meetings, Writing, Oral Presentations
Project Management
Rational Management Processes
Safety Practices

Course Details: CHE 101 Chemical Engineering Orientation

The OSU College of Engineering prides itself in providing its students with a highly personalized education. In the Chemical Engineering Department, first year students are introduced to the field of chemical engineering from the first day (literally) they are on campus through the CHE 101 Introduction to Chemical Engineering course. As with most orientation courses, the CHE 101 course was developed with the primary purpose of "introducing" students to the subject area. In this case, not only are we trying to introduce new subject matter, but we are also trying to help students make judicious career choices. The Course Learning Objectives (CLO), which were developed to meet the ABET 2000 Criteria 3 (a-k), provide a good outline of how we hope to accomplish this.

CHE 101 Course Learning Objectives

The students will demonstrate the ability to:

1) comprehend and define the nature of the Chemical Engineering Profession. What is Chemical Engineering? What do Chemical Engineers do? What skills do ChE's need to be successful?

2) comprehend and define the roles of Oregon State University (OSU), the College of Engineering (COE), and the Chemical Engineering (ChE) Department. in undergraduate education.

3) apply basic engineering skills for a successful engineering career at OSU and beyond.

   a) use computers for: word processing (WORD); spreadsheet analysis (EXCEL) of engineering data; drawing of engineering flowsheets (Power Point or WORD); presentations (Power Point) , email correspondence, and internet access of information.

   b) use basic engineering problem solving skills in classroom and laboratory environments.

   c) work in TEAMS in the classroom environment to "brainstorm" for process analysis, engineering problem solving, ethics discussions, ChE career discussions, etc.

   d) work in TEAMS in a laboratory environment to plan, design, and implement experimental solutions to common engineering problems such as fluid flow in pipes (f vs. Re and fluid viscosity), heat transfer (adiabatic vessels), leaching and mass transfer (brewing tea), etc.

   e) use proper communication skills in oral (presentations and team discussions), written (memos, letters, and laboratory reports), and email correspondence.

4) work as part of a TEAM on an open-ended design problem related to chemical engineering (AIChE Student Chapters Chem-E-Car Competition), which involves time management, planning, design and re-design, data collection and analysis, oral and written communication, and a deliverable product.

The end result, as gauged by student survey responses, was a challenging and fun project. The students learned to work in teams; deliver weekly progress reports; design, build, test, and re-design; and deliver a "product" on a timeline. The final day Poster Session and RACE were a ChE Department "event", with all levels of students cheering for the race competitors ("Team Cool", "Team Pull my Finger", Noel and the Nunnery, etc.). Senior students were heard commenting that "they never got to do anything fun like this in CHE 101". The freshman students comments were predominantly positive, with many saying they got the most satisfaction from initially being "afraid and confused" about how to go about designing the car, to being relieved when it actually moved, to being "exhilarative" and "competitive" on RACE DAY. The winners came within 3cm of the 25 ft mark….quite an achievement! All the freshman students recommended that we repeat the project in the following year…and many of the older students want to "retake" CHE 101!

Project Details: CHE 102 Chemical Engineering Computations

CHE 102 is the course where first-year students are introduced to chemical engineering calculations done using computer software. Traditionally this included an introduction to a programming language such as FORTRAN or C, but more recently the MATLAB® package from The MathWorks, Inc. has been used. In addition, as shown on the first page of the syllabus included in the Appendix, the students solve simple problems using the flowsheet software ChemCAD®, which they use in later classes. Although these software tools are very valuable for a chemical engineer, the first-year students generally considered this a less enjoyable course than the orientation course of the previous quarter. This year to increase enthusiasm and engage students more in programming, we decided to demonstrate real-time programming and data logging. We incorporated ROBOLAB software and the LEGO RCX brick in a project which involved mobile data acquisition and held a "tournament" at the end of the quarter to determine the best design/performance of a student team's robot.

The challenge to the students was to build and program an autonomous robot that would follow a course line on the floor through two regions of high temperature while recording position and temperature readings. At a designated finish line the robot was to stop and give an audible signal which indicated whether the first or second temperature peak was larger. A schematic diagram which indicates the geometry of the course is shown in Figure 2.

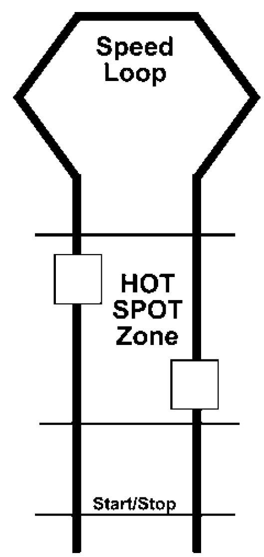

Figure 2

All of the students were very familiar with LEGO sets, but none of them had used a Mindstorms® set or the RCX microcontroller. As an introduction to the use of the Technic pieces and RCX, students were first assigned a temperature sensing experiment. In this experiment a styrofoam box is heated by a light bulb until steady state is achieved.

Then a fan powered by a LEGO high speed motor is turned on and the temperature recorded as the box cools. Students were given a copy of the DACTA set #9790 (about $200). Although the tasks at first seemed to be only slight extensions of previous exercises, the student soon realized there were a variety of engineering decisions and tradeoffs to be made. Some of these differences are shown in the table below.

	Bench Scale	Tournament Scale
Surface	black ink line drawn on brown wrapping paper	black electrical tape placed on white masking tape
Length	about 1.5 meters	about 15 meters
Environment	table top, normal lab lighting	classroom floor, variable lighting depending on weather
Tasks	follow curves	
Data logging	initial heater box, none with robot	two heater boxes on course, extreme brightness inside boxes will change light sensor readings if not shaded
Logic	only line following using light sensor	line following + speed "shifting" dependent on location and temperature readings, possibly stopping for to measure temperature

Originally the robots were to be run once in either direction over the course, but time constraints allowed only a single run from the right starting point. Thus robots executed a right turn, then four turns to the left followed by a final right turn in the competition. If at the end of the run there was a problem retrieving the data, the robot had to repeat the course, since a mandatory part of the written report was an analysis of the temperature versus distance based on the two data files: one for temperature and one for rotation counts.

The results of the tournament format were very rewarding. Out of twenty teams, nine were able to have their robot stop within on 9 inch floor tile of the designated finish line. The tournament attracted upperclass CHE students, friends for other engineering department, faculty and several alumni. Each robot's run was accompanied by a song chosen by the team and submitted on a CD. The biggest crowd pleaser was an RCX programmed to play the Mario Bothers theme prior to the same music playing from the CD. The written reports from the teams will form the basis of an extended project manual with tips on building and programming so that next year's competition should be even keener.

Conclusions

For a relatively low cost we have greatly enhanced the hands-on component of our first-year courses through the use of LEGO sets. Both chemical and engineering principles were utilized by student teams to design and improve systems to achieve multiple objectives. Student feedback is overwhelmingly positive, even though this was the initial implementation of the projects and some "rough spots" naturally arose. We anticipate continual improvements will be made and that detailed instructions will become available to other schools who want to implement the "Lessons with LEGO" projects.

Biographical Information

KEITH L. LEVIEN

Keith Levien has an engineering science degree from Iowa State University (BS) and degrees in chemical engineering from the University of Wisconsin, Madison (BS and PhD). Between chemical engineering degrees he worked for four years at the Warrensville Research Center of SOHIO (now BP). His research is in reaction engineering, process control, optimization and supercritical fluid technology.

WILLIE E. (SKIP) ROCHEFORT

Skip Rochefort has degrees in chemical engineering from the University of Massachusetts (BS), Northwestern University (MS), and the University of California at San Diego (PhD). He worked at Dow Chemical, Kodak Laboratories and AT&T Bell Laboratories. His research is primarily in biomaterials, high strength plastic materials, wood/recycled plastic composites, and engineering education -- getting high school students interested in engineering careers!

CHE 101: AIChE Chem-E-Car Competition (C^3)

(LEGO® Modified)
Department of Chemical Engineering
Oregon State University

The 2001 CHE 101 Freshman Orientation Final Term Project is a modified version of the **National AIChE Student Chapters Chem-E-Car Competition (C^3).** The complete RULES governing the AIChE Student Chapters Chem-E-Car Competition (C^3) are posted on the AIChE web site at: **http://www.aiche.org/students/competition/c3car.htm**

The rules modifications for the CHE 101 Final Project are as follows:

1) Teams have only five (5) weeks to complete the project.
   Final Competition will be Friday, November 30, 2001.

2) All teams will be issued **LEGO CREATOR** kits from which to build their cars.

3) Total cost must be < \$25 (excluding LEGO kit) and pre-approved by Dr. Rochefort.

4) There is a pre-determined load and distance: **load = 100 ml water, distance = 25 ft.**

5) Teams will be composed completely of freshman students.

DELIVERABLES

1) POSTER and ORAL PRESENTATION (team members)
- Description of the chemical reaction used to power the vehicle
- Vehicle Design -- unique features and design creativity
- Experimental Data and Data Analysis (representative)
- Environmental and SAFETY issues must be addressed

2) REPORT
- Description of the chemical reaction used to power the vehicle
- Vehicle Design -- unique features and design creativity
- Experimental Data and Data Analysis (complete)
- Environmental and SAFETY issues must be addressed
  - this MUST include a Materials Safety Data Sheet (MSDS) for all chemicals used.

3) LEGO CAR Competition – RACE DAY
- vehicle capable of performing to a "minimum" level (it has to at least move)
- AWARDS will be given to 1st, 2nd, 3rd place finishers based on the "race day" results

NOTICE: Any group or vehicle found violating SAFETY rules will be disqualified. If you have questions about a SAFETY issue, please check with Dr, Rochefort in ADVANCE!

CHE 102 (3cr.) - Introductory CHE Computation

Winter Quarter 2002
Department of Chemical Engineering
Oregon State University

CHE 102. INTRODUCTORY CHEMICAL ENGINEERING COMPUTATION (3).
Application of spreadsheets, structured programming and chemical process simulation software to solve a variety of chemical engineering problems. Lec/rec.

Lec. **F** 1-1:50pm OR 2-2:50pm, Rec. **M,W** 1-2:50pm, meetings in Gleeson **200** or Schulein computer lab (room 002) or LEGO® Lab (room 204) in Gleeson Hall

Instructors: Dr. Keith L. **Levien**, Room 203 Gleeson Hall 737-3155,
levienk@engr.orst.edu, Off. Hrs.: **T-F** 3-3:50pm or by appointment
Dr. W.E. (Skip) **Rochefort**, Room 205 Gleeson Hall 737-2408,
rochefsk@engr.orst.edu, Off. Hrs.: **MTWF** 11am-1pm or by appointment,
lab = Gleeson 206
Debra **Johnson**, Room 303 Gleeson Hall 737-8990,
johnsodl@che.orst.edu, Off. Hrs.: **T** 10-10:50, noon-2:50pm

Mentors: Janelle Mangini (mangini@engr.orst.edu) and James Walter(james_walter@juno.com), will hold help sessions in LEGO® Lab, room 204, **MW** 3-4:50, **TR** 1-2:50 for MATLAB/ROBOLAB help

Text: Palm, William J. III, *Introduction to MATLAB 6 for Engineers*, McGraw-Hill, 2001, ISBN 0-07-234983-2. This is part of McGraw-Hill's Basic Engineering Series and Tools.

Refs: MATLAB online help or www.mathworks.com, also an online MATLAB text using the Prentice-Hall code in the CHE 101 textbook.
ROBOLAB help at:
(1) www.lego.com/dacta/robolab/programmopedia.htm
(2) www.ceeo.tufts.edu/graphics/moreonrobolab.html

Grading:

HWs + Labs =	20 %	
ROBOLAB Proj.* =	20	written report due Tues 3/19 2pm (at Final Exam)
Instructor Eval. =	5	(participation, attendance, effort)
Simulink Project* =	10	written report due Fri. 3/15 by 3pm
2 Exams =	30	(Feb. 1, Mar. 1) = MATLAB based
Final Exam =	15	(comprehensive covering course learning objectives)
	100 %	

* = written reports done 1 copy per "programming" team = 2 or 3 students

CHE 102 - TEAM Design Project: Definition

Department of Chemical Engineering
Oregon State University

The TEAM Design Project is performed by student teams with 2 or 3 members on a programming team. Two programming teams work together using one of the LEGO® Team Challenge Kits. These kits are numbered 1-10 and stored in Room 204 Gleeson Hall (the "LEGO Lab"). There should be 10 different mechanical designs of the project robot among teams in the class, but 20 different programs for solving the project challenge.

OBJECTIVES:

Work as a team to design a robot using the pieces of the "extended" LEGO® Team Challenge Kits in Room 204 and program it using ROBOLAB® "Investigator Level" to perform a variety of tasks. The extended kits include a rotation sensor as well as the two high speed motors, temperature sensor and propeller used in the heater box experiments. Each product design will be evaluated by judges on the following criteria:

1) Structural design	10 pts max (strong, efficient, original)
2) Programming design	20 pts max (clear, robust, efficient)
3) Aesthetics	10 pts max ("looks/excitement")
4) Performance	60 pts max (quantitative - see criteria)
Total	100 pts max

CHALLENGE PERFORMANCE TASKS:

On "tournament day" your robot should demonstrate the ability to:

1) rapidly and accurately follow a course marked by black electrical tape on a masking tape background on the floor of room 200 in Gleeson Hall - points deducted for leaving the line (no short cuts !!)

2) monitor environmental temperature and use measurements to evaluate two temperature "peaks" along the course. The robot must evaluate WHICH of a "first" or "second" encountered "local peak" temperature is the larger and report that choice as one "beep" or two "beeps" at the end. The robot should display this larger temperature as a number on its LCD panel. It must have stored a temperature "history" it found along the path as well as the distance travelled.

3) the robot must monitor the total distance it has travelled and STOP at a designated point near the end of the course line.

Only a single ROBOLAB program can be used in your RCX.

APPENDIX

CHE 102 - TEAM Design Project: Introduction

Department of Chemical Engineering
Oregon State University

MDA = Mobile Data Acquisition, the LEGO® RCX-controlled robot doing ......
"Hotspot Hunting"

Project Team =	2-3 students working on unique programming solution using Investigator level of ROBOLAB v2.0
Design Team =	combination of two project teams (4-5 students) which will share a mechanical design made only from the pieces of a single "extended" DACTA #9790 Team Challenge sets available in Gleeson 200.

LEADERSHIP DESIGNATION (responsibility)

A team leader, but more like -> the "pilot"

Since some teams have only 2 people,
the other person would be -> the "copilot"

The "pilot" is someone responsible for assuring timely progress: time management and coordination, but if some personal problem arises, the copilot is fully capable of getting the project completed.

ROLE ACCEPTED (sorts of things an individual would do)

"designer" =	mechanical design (Technic hardware)
"programmer" =	program design (ROBOLAB software)
"historian" =	data/design documentation: records and evolution (CAD: LEGO Designer® software), final ROBOLAB diagram with written description of how it works
"analyst" =	use MATLAB to plot data taken, make tables, check experiments for reproducibility
"editor" =	responsible for pulling together contributions for final written report

APPENDIX

A testing course will be set up in Gleeson 200 so you will be able to try the basic scooter design with rotation sensor for measuring distances while taking temperatures.

I would expect today:

(1) the "designers" from each team should sit down and make some decisions based on some compromises on what they want to do for their mechanical design

(2) Meanwhile the programmers should be looking at ROBOLAB to figure out a program that would take temperature readings like the hot box experiment, follow a line and measure a distance all at the same time. I will provide a copy of a program written by the middle school team to use the rotation sensor.

(3) While designers & programmers discuss ideas, the other team members should build the scooter (if no mechanical design is done yet) with light, rotation and temperature sensors all installed, following the instructions for the light+rotation sensors in the lab books and figure out a way to connect and mount the temperature sensor.

I would expect (2) and (3) to get something done within an hour of the groups being done with the role/tasks exercise. Then the designers may have time to make some changes or totally revamp the mechanical design based on how things work out with the initial ideas from (2).

That's just my expectations if you get down to business and try something. The IMPORTANT concept is to at least get SOMETHING working on part of the problem, then get it all to work, then improve upon your "feasible" design.

You should NOT get hung up on trying to solve the problem with a traditional sequential approach to an assignment without trying out your ideas, so "discussion/debate" time should be short compared to "action/experiment" time.