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Conducting Project-based learning with a large chemical engineering freshman cohort using LEGO NXT robotics

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Abstract

The focus of this paper is the use of project-based learning in a freshman chemical engineering studio environment.

Perhaps at no other time in a student's academic career will you find such a high level of anticipation for learning coupled with an equally high level of curiosity about their chosen field of study. The challenge presented is to capture and direct that eagerness for learning while motivating students to persevere through a coming tidal wave of challenging course content that is virtually ceaseless over the course of the freshman year.

Engaging chemical engineering freshmen in project-based learning brings decided advantages to the first-year engineering experience when compared to the traditional "orientation" format. This paper reports on a first-year experience in chemical engineering using a series of project-based learning exercises integrating the LEGO™ NXT Robotics system coupled to Vernier® sensors and probes and "in house"-designed apparatus. Activities have been designed to introduce students to a sequence of increasingly complex "team challenges" requiring student teams to design, test and refine process controls systems for physical and chemical phenomena commonly encountered in chemical engineering practice (e.g. level control, temperature control, reactor design and process economics).

Our first year chemical engineering course sequence herein reported engages a large freshman cohort (around 100 students, at present) in team-based, hands-on activities. Evidence suggests students readily "latching onto" key concepts and various aspects of chemical engineering through this "multi-modal" learning approach. Objectives of this method of program integration include: 1) strengthened retention of freshmen in our chemical engineering program, 2) better "visualization" of chemical engineering concepts among chemical engineering freshmen and 3) a stronger sense of the application of STEM topics to the professional practice of chemical engineering.

Introduction

The freshman engineering experience can bring an almost overwhelming assortment of information to be grasped, assimilated and synthesized into the student's framework of understanding. Often, the myriad of facts appear to stand in isolation, with little to no apparent interrelation. The desire of freshmen engineering educators to aid students to contextualize all of this information can be particularly challenging when facing a large student cohort in the Introduction to Engineering courses—with a large and varied degree of prior preparation, learning styles, and preconceptions about their reasons and motivations for entering engineering. Over the past eight years, the freshman Chemical Engineering Analysis course (offered each spring semester of the freshman year) has provided an evolving and increasingly enriched environment for experimenting with project- and problem-based learning to help first-year chemical engineering students gain a better grasp on the "mysteries" of the fields of engineering (with emphasis, of course, upon chemical engineering). Additionally, the freshman orientation course (a one credit hour course taught each fall semester) is being modified to better integrate with the spring Analysis course—providing a full first year engineering studio experience in problem- and project-based learning. By integrating these two courses and using project- and problem-based learning techniques, the first year chemical engineering students have a unique opportunity to see their STEM topics come to life in an active learning environment with practical engineering applications.

The use of project-based learning and the closely associated problem-based learning as vehicles for improving learning across a spectrum of learning styles has a long and well-documented history in both K-12[1-3] and in higher education[4-7]. While there are distinct differences associated with these instructional approaches, a blending of these two pedagogies best describes the evolution of the Analysis learning environment.

Project-based learning opportunities include:

- Students engaging in research, design and development activities directed toward achieving a particular need or objective
- The project investigation spanning an extended period and a range of learning outcomes
- Students using multiple learning skills during the project lifetime
- Multiple informational resources being used for approaching the project.

Though seemingly nuanced in comparison to project-based learning, Problem-based learning characteristics include:

- Students providing definition and clarity for a potentially vague or ill-defined problem
- Solutions to the problem methodically and iteratively developed
- The problem being narrower in scope in comparison to the "project-based" approach.

Through Introduction to Chemical Engineering (one credit-hour offered each fall term) and Chemical Engineering Analysis (a three-credit hour studio offered each spring) , our freshmen, in a class size of 80-100, are engaged in a seamless, two-semester problem-based learning experience.

Course structure to accommodate *PBL*

Through a series of "Team Challenges" (i.e. design projects and experimentation) our freshman cohort engages in activities focused on fundamental STEM concepts and applications to help them better visualize and understand the path they have started on to enter engineering practice. Figure 1 illustrates the range of topics covered in Learning Outcomes established for the first year experience. To enable sufficient time obviously needed to cover such a broad range of topics, the Analysis course comprises one credit hour of laboratory and two credit hours of lecture (under the traditional definitions of "lab" and "lecture"). This credit structure provides for two two-hour and forty minute sessions "in studio" each week.

Studio-environment with a large cohort

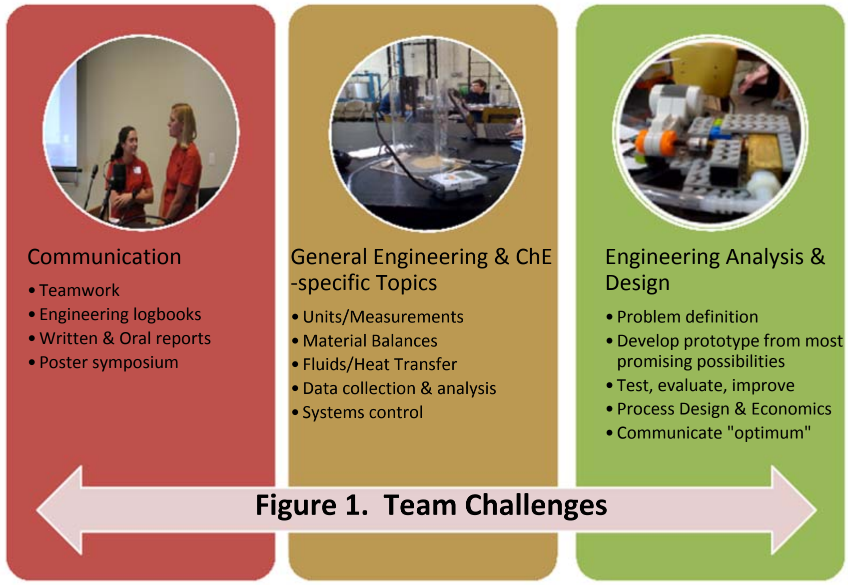

Figure 1. Team Challenges

Significant growth is currently underway in chemical engineering programs throughout the country. Our freshman cohort has grown steadily over the past five years from an enrollment of 65 in 2010 to 96 for the spring 2014 semester. To engage a large section of students simultaneously in a studio environment has presented significant challenges with regard to space and resource allocation. A 160 seat auditorium is available for discussing projects and important topics with the entire group. But it is not suitable for Team Challenge activities. A small "dry lab" (~800 ft^2) can accommodate up to seven teams (of four students each). Since I also direct our junior and senior level Unit Operations laboratories (laboratory courses common generally all chemical engineering programs), I can coordinate use of space in those lab areas to accommodate activities for student teams engaged in projects requiring ready access to water, the chemical storeroom, etc. The Unit Operations laboratory area comprises over 3000 ft^2 of available instructional space. Lab stations for 25-30 student teams can thus be accommodated. Resources for the studio are covered, in part, from a student laboratory fee. Since I also use many of the materials with our active K-12 Outreach program (through the American Institute of Chemical Engineers or AIChE student chapter) some support originates with an endowment dedicated to AICHE and the undergraduate program.

From the earliest days of this initiative, my goal has been to engage students with materials they could quickly put into use so that they might focus on the learning outcomes. Having coached middle-school teams in First® Lego® League, I saw the potential adaptability of LEGO NXT kits for a range of projects and activities well-suited to freshman engineering. With base kits under $300, the LEGO NXT robotics set is very cost effective. Many students are very familiar with LEGOs. When I point out to my class that the NXT robotics kit label lists the product for ages 8^+, students grin appreciatively and are quickly underway creatively design and programming. I have observed that the programming phase is daunting to some students. To keep them engaged I am restructuring the Spring 2014 semester Analysis course to more frequently assess all students' progress on programming. While chemical engineers are in no way charged with programming as a regular feature of their job responsibilities—the systematic, organized approach to problem solving required to structure even a simple controls program IS a very useful exercise. It provides students an opportunity to clearly analyze and evaluate their proposed algorithm for solving a particular problem. When the LEGO NXT robotics kit is coupled with Vernier sensors and systems of tanks, piping, pumps (some of which is assembled in-house), the replication of a number of units for a large number of student teams is readily accomplished.

Team Challenges

For spring 2014, the course is centered on a series of four Team Challenges, each with a different assortment of desired learning outcomes. Student teams will rotate through each of these four Team Challenges spending three weeks on each project. Within the three week cycle the teams will perform a series of activities to investigate a particular problem, and, where appropriate, to design, build and test a solution—successively refining the solution to improve.

The four challenges are:

1. Learning about heat transfer in a double-pipe heat exchanger
2. Design, optimization, and economics of a simple solar oven
3. Process control for maintaining tank level
4. Estimation of thermal conductivity for a series of unknown metals

Learning Outcomes common to all four Team Challenges are:

1. Know and work with your team members more effectively to approach technical problems using a systematic approach (similar to the Engineering Design Cycle or Scientific Method).
2. Be capable of keeping accurate, detailed records in an engineering logbook and translate that work into an organized report that would allow someone unfamiliar with this experiment to repeat your experimental work.
3. Demonstrate the ability to use appropriate modern engineering tools (e.g. programming software and Microsoft Excel®) to complete the project, acquire and process experimental data and make appropriate calculations and interpretations of the physical phenomena being studied.

I am convinced that a key component to student success in first year engineering is the establishment of strong, productive working relationships among the students. Learning Outcome 1 focuses on this aspect of the first-year experience. The importance of students practicing critical teaming skills (e.g. teamwork, leadership, collaborative learning, and conflict resolution) is pervasive in the educational literature. Each Team Challenge is structured to lead students from the early chaos of team formation and problem definition to the successful completion of solving a technical problem.[8]

Learning Outcome 2 focuses on the group dynamics required to translate the results from the Team Challenge exercise into a common communication for assessment (i.e. submitting oral and written reports to team mentors, the Instructor, or a team of judges—as in the case of the poster presentation at the semester's end). Each Team Challenge project offers students the chance to hone their technical and communication skills and the application of STEM topics to practical problem solving—skills essential for student success throughout the remainder of their engineering studies and, when practiced and honed appropriately, will carry into career pursuits with a strong potential for success. Each Team Challenge is summarized in a group written report. To strengthen group member participation, each member is assigned a particular task within the team (i.e. Team Leader, Safety Officer, Data Recorder, Experiment Analyst). In addition to specific duties to perform during the actual project, each position is assigned a specific set of report sections to write. Eighty percent of the report grade is awarded upon the basis of the student's individual writing of his/her report sections and 20% derives from the overall report average. The increased accountability has been shown to improve overall group performance and individual student participation.[9]

Like all of the Learning Outcomes associated with this course sequence, the Learning Outcome 3 closely matches guidelines provided by the ABET (Accreditation Board for Engineering and Technology) Student Outcomes. The studio setting with PBL is ideally suited for students to practice use of modern engineering tools. Microsoft Excel® is commonly used in the chemical process industries as a tool for tracking process units (e.g. production rates, utilities, etc.) among many other applications. Students entering the co-operative education program in the chemical process industries may often find they are given a project requiring extensive use of Excel during their co-op rotation. A few of our freshmen will enter the co-operative education program the summer following the freshmen year. A significantly higher number will begin the spring term of their sophomore year. Thus the high number of our students participating in the co-operative education program (historically, 67% of our graduates) makes the use of Excel for data processing, graphing, basic statistical analysis, etc. an important and timely feature of our first-year experience.

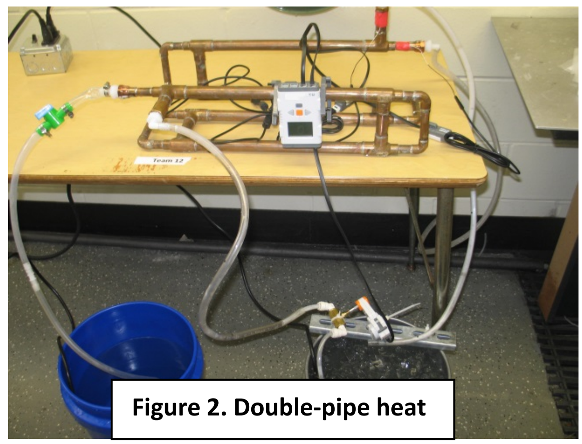

Figure 2. Double-pipe heat

Example Team Challenge—Learning about heat transfer in a double-pipe heat exchanger

An overview of the double-pipe heat exchanger project illustrates the nature of a Team Challenge. Figure 2 shows an example double-pipe heat exchanger (constructed by students in one of my past heat transfer classes). A "hot" process stream (tap water) flows from a reservoir (blue tank in the picture) equipped with a small submersible pump. The water flows through a manually controlled valve (green valve shown at left) and through the "tube side" (i.e. inner ½" copper tube) of the double-pipe heat exchanger. A cold stream (ice water) is fed to the "shell side" (i.e. a ¾" sealed copper tube) to cool the process stream to a specified temperature.

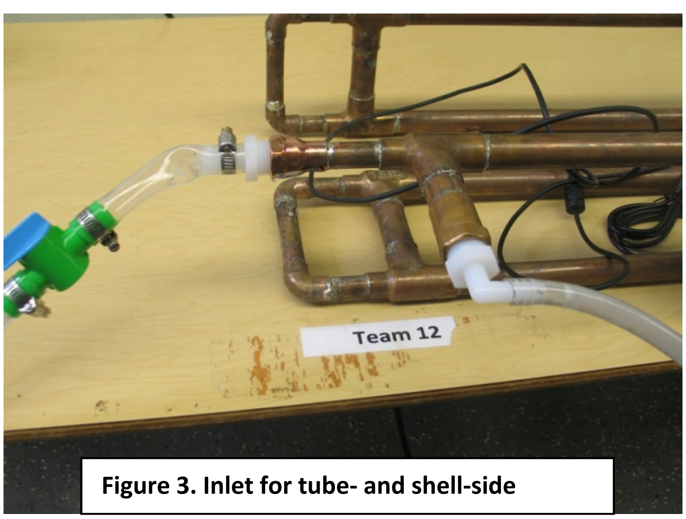

Figure 3. Inlet for tube- and shell-side

Figure 3 shows the inlet hot and cold streams to the tube-side and shell-side pipes, respectively. Students collect performance data for four separate process stream flow rates. The flow rate of the process stream is to be controlled manually by fixing the green valve full open, and approximately ¾ open, ½ open and ¼ open.

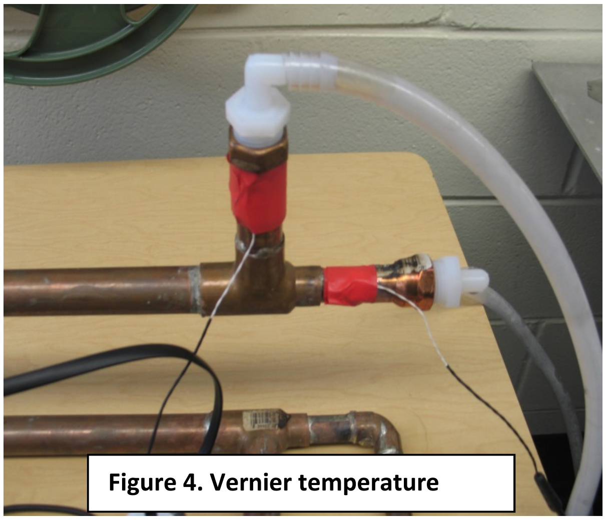

Figure 4. Vernier temperature

To achieve the specified temperature control of the outlet process stream, a LEGO NXT controller (in Figure 2, shown suspended from the double-pipe exchanger) receives temperature information from two Vernier surface probes (Figure 4, white lead wires under red tape) placed at the outlets of the tube-side hot and shell-side cold streams, respectively. This information is used to automatically adjust the flow rate of the cooling water using a flow control valve affixed to the cooling water reservoir (Figure 5). Volumetric flow rate data is taken for both the process stream and the cooling water stream at each settings to conduct heat balance calculations.

In Figure 5, a stainless steel coupling is shown connecting the LEGO control motor to the valve stem. Also shown is the submersible pump (ice was removed from the cooling water reservoir for clarity). The cooling water flow rate is adjusted automatically by a student team-developed control program which opens/closes the control valve to maintain the desired set point temperature of the exiting process stream.

During operation, the student team must keep the process stream reservoir filled to a constant level as the processing stream exiting the heat exchanger is discarded (to avoid changing the inlet temperature of the process stream—thus preventing the system from reaching a thermal steady-state). The level must be maintained to ensure a constant flow rate (as significant changes in static pressure head will affect the flow rate for size pump used). The water exiting the cooling water pipe is returned to the cooling water reservoir as the ice bath temperature remains virtually constant over the course of each experimental run.

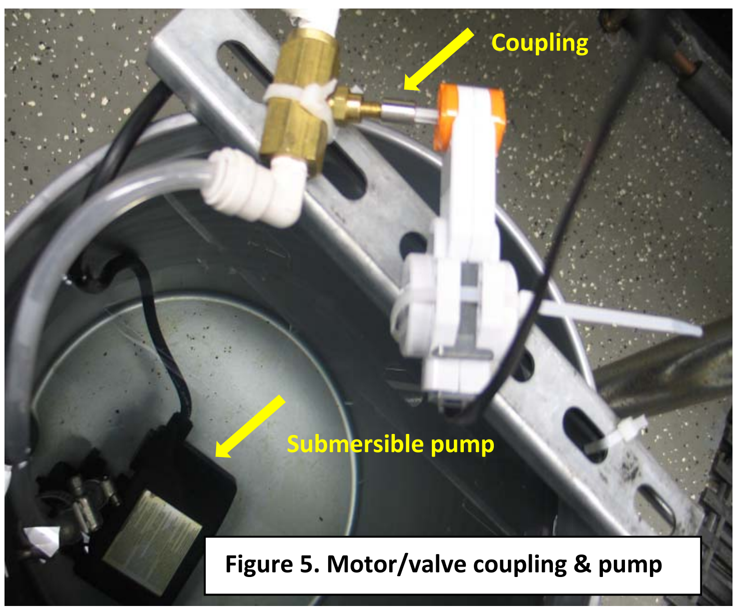

Figure 5. Motor/valve coupling & pump

Learning Outcomes specific to this Team Challenge are:

"At the end of this Team Challenge you should be able to…

1. Describe fundamentals of the following heat transfer concepts:

- the use of the bulk heat equation for determining rates of heat gain by the cooling water stream and heat loss by the hot process stream
- determine the Overall Heat Transfer Coefficient using Newton's law of cooling and the concept of the log-mean temperature difference

2. Demonstrate the use of the Engineering Design Process (Figure 6) for iteratively improving temperature control in successive experimental runs (at each of the specified process stream flow rates).

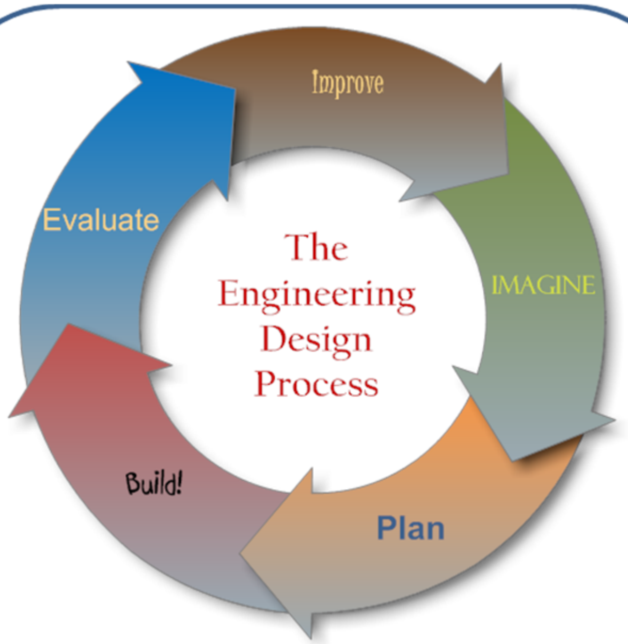

Figure 6. Engineering Design Cycle

3. Plot process stream exit temperature and the overall process stream cooling and cooling water heating rates versus time (for each set of experimental conditions). Explain the meaning of transient and steady-state using experimental data plotted in Microsoft Excel®. In the spring 2014 offering of Analysis, the link between Excel techniques and the analysis of the experimental data acquired through each Team Challenge project has been strengthened. In the early stage of this current offering, students are providing encouraging feedback about the value they see in this approach. "I helped my mom analyze data from her research project at work" stated one student enthusiastically after a weekend trip home. "Doc, in a co-op job interview just after our test, I was asked about the things we are learning in our freshman year and the interviewer was very impressed when I talked about analyzing heat exchanger performance in our Team Challenge".

4. Discuss the importance of repeatability in engineering experimentation using basic statistical analyses."

These Learning Outcomes appear daunting when isolated from course materials and classroom discussions. However students have responded to the Team Challenges enthusiastically. Anecdotally, student responses after completing the course have covered a broad range. Comments like "I learned a great deal in this class, most importantly that I shouldn't be a ChE" or "Wish I wasn't changing my major" are disappointing, to be sure, but valuable and timely for freshmen needing confirmation of their career preparation. And as much as I would like 100% retention, engineering just isn't for everyone. Others (the vast majority) respond positively. Comments like "This course rocks!", or "I feel they [the projects] helped me make sure I wanted to be a ChE", or " I can't wait to get into fluid mechanics!" (a first semester sophomore course in our curriculum) bring strong affirmation of this approach to the first-year engineering course.

Observations, Assessment and Conclusions

As the course has evolved over the nine years I have taught it, I have moved from a more open-ended project format to one where the projects have a "tighter" design window. For example, a past Team Challenge requiring pH control in a mixing tank involved students assembling "from scratch" a completely automated systems from an assortment of disconnected pipes, pumps, and tanks (along with their LEGO NXT and Vernier equipment). The time required to successfully see such a project through to completion has proven too long for the completion of multiple projects in one semester. In the latest iteration, each project (other than the solar oven design project) consists of a partial or completely assembled experimental apparatus.

1. *Learning about heat transfer in a double-pipe heat exchanger*—this project (previously discussed) is fully assembled, allowing teams to focus on their control design scheme and acquiring experimental data under different operating conditions.

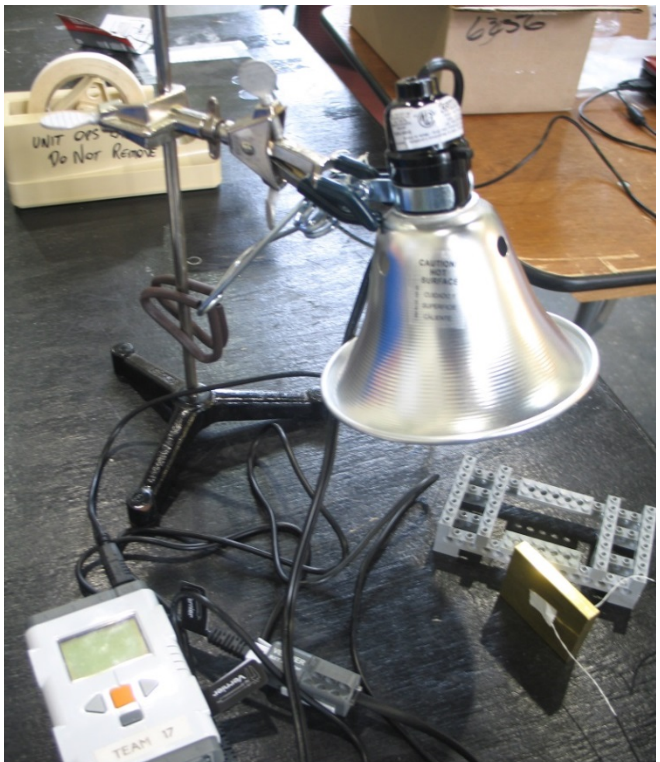

Figure 7. Thermal Conductivity Team Challenge

2. *Estimation of thermal conductivity for a series of unknown metals*—(Figure 7) is likewise fully assembled to allow maximum time for investigation of the physical phenomena with multiple experimental runs. A primary Learning Outcome from this project is statistical treatment of large data sets. Students will apply statistical methods using Microsoft Excel® to evaluate statistical significance of variations in data.

3. *Process control for maintaining tank level*—this project requires design of an apparatus to integrate an ultrasonic sensor (for tank level detection) with the tank/pumping system. Student teams must use the engineering design cycle (Figure 6) for iteratively testing and improving their process design. A primary Learning Outcome specific to this project is the understanding of basic terms in automated process control and the ability of the students to successively refine a programmed control scheme to improve level control.

4. *Design, optimization, and economics of a simple solar oven*—this project requires the greatest amount of creativity as student teams must design, build and test the solar oven from raw materials provided. Provided with a cardboard box, foil, a transparent food wrap, and duct tape, teams must design and construct a simple solar oven given volume and surface area constraints. Experimental data is obtained for the rate of heating and the ultimate temperature as a function of aperture size through which the "solar energy" (from a heat lamp) is supplied. A Learning Outcome unique to this project (in comparison to the others described) is the requirement for the teams to conduct a simple

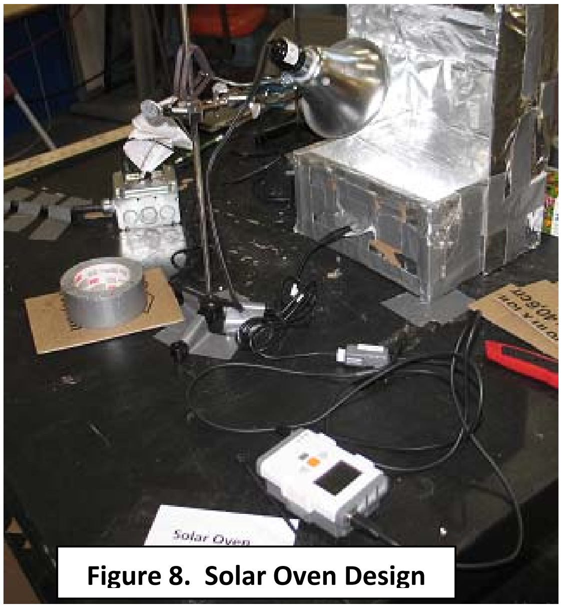

Figure 8. Solar Oven Design

economic analysis of the materials of construction and a simple energy balance to evaluate oven performance.

Conclusions

Major changes have accompanied the freshman year course sequence in our chemical engineering program. The introduction of a problem-based/project-based learning approach and restructuring the first year experience around a studio environment has been met with strong and enthusiastic support from all constituent groups (students, faculty, advisory board members and alumni). The assessment conducted in the course, to date, comprises regular evaluations of individual student performance, periodic surveys of students regarding their perceived growth and understanding, an end-of-semester "faculty evaluation" survey, and an Instructor Course Assessment.

Table 1 shows student ratings for two general assessment questions including in faculty evaluations at the conclusion of each course. The generality of the questions and the evolving nature of the first-year course sequence prevent quantitative comparisons of the data. Yet, a generally positive trend is clear from the earliest stages of this course offering.

Table 1. Sample ratings from the faculty evaluation survey

Year	**"I learned a great deal in this class".** Rating* (out of 5)/No students	**"The Presentation of Course Content helped me learn in this class"**
2013	4.5/71	4.2/71
2012	4.5/55	3.9/55
2011	4.5/34	4.4/34
2010	4.3/53	4.3/53
2009	4.3/35	4.2/35
2008	4.0/51	4.0/51
2007	3.6/19	4.0/19
2006**	NA	NA
2005**	3.19/30	3.79/30

*The rating is conducted on a five point scale—1=Strongly Disagree, 5=Strongly Agree
**Survey questions in '05 & '06 were worded somewhat differently.

Scoring rubrics are being developed for the current structure of both the new Introduction to Chemical Engineering studio (fall 2014 term) and the revised Chemical Engineering Analysis studio (spring 2014 term) to assess student performance and for evaluating student perceptions of their own growth in understanding and confidence in pursuing chemical engineering. Results from assessment activities in the early stages of the Analysis course evolution indicated that the difference between students' expectations and perceptions was significantly related to their academic, team, and career efficacy. Additionally, the change in efficacy over the semester was significantly related to student satisfaction.[10] The aim for future assessment is to better quantify self-efficacy of our students and attempt to directly link it to their progression through the first year experience. The varying nature of activities required for student teams in each Analysis Team Challenge may afford the ability to treat sub-sets of teams (working on a particular project) as a control group for comparison with other team sub-sets when attempting to ascertain the effects of particular project activities upon certain skills development and student self efficacy. An anonymous survey administered after completion of the first Team Challenge (spring 2014) evaluated students' on six questions related to Learning Outcomes. Students were asked to rate their perceptions both before and after completing the Team Challenge on a five point. The following results were obtained:

ChE 2213 Analysis—Team Challenge #1 Survey				
Please rate your each of the following questions regarding your perceived progress made Before and After Team Challenge #1 **1=No substantial Progress; 2=Small amount of progress; 3=Moderate progress; 4=Significant progress; 5=Enormous progress**				
Rate your ability to…	Average Before Team Challenge #1	Average Before Team Challenge #1	Δ Averages	StdDev
Analyze fundamental chemical engineering problems and systematically develop appropriate solutions	2.4	3.9	1.5	0.73
Use basic Excel tools to collect & analyze data from your engineering designs and use this process for making design and performance improvements	1.9	3.9	2.1	1.12
Employ the Engineering Design Cycle for approaching your project and for making improvements in the process or design.	2.9	3.9	1.0	0.88
Work with your team members to solve problems that arise.	3.3	4.2	0.9	1.21
Move a technical problem from a word description through defining it with appropriate concepts, symbols and equations to reach a solution.	2.6	3.9	1.4	0.91
Explain to someone in your family (or a non-engineer) what chemical engineering is about—giving practical examples	2.3	3.9	1.7	1.04

While these results are inconclusive (and obtained very early in the spring 2014 offering of Analysis, there clearly is an indication that students perceive a significant boost in their perceptions of improved abilities for achieving the course Learning Objectives. Further analysis will allow a more definitive assessment of the course improvements.

References

1. Lund, H. H.; O. Miglino; L. Pagliarini; A. Billard; and A. Ijspeert; *Evolutionary Robotics—A Children's Game;* In Proceedings of IEEE 5th Intl. Conf. on Evolutionary Computation; IEEE Press, NJ, 1998 . From the link http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.35.6283&rep=rep1&type=ps

2. Chambers, J., Carbonaro, M., & Rex, M. (2007). Scaffolding Knowledge Construction through Robotic Technology: A Middle School Case Study. Electronic Journal for the Integration of Technology in Education, 6, 55 – 70. From http://ejite.isu.edu/Volume6/Chambers.pdf

3. Kolodner, J.; P. Camp; D. Crismond; B. Fasse; J. Gray; J. Holbrook; S. Puntambekar; and M. Ryan; *Problem-based Learning Meets Case-based Reasoning in the Middle-School Science Classrom: Putting Learning by Design™ into Practice;* J. of Learning Sciences; 12:4 (2003) pp.495-547.

4. Maida, C.A. (2011). Project-Based Learning: A Critical Pedagogy for the Twenty-First Century. *Policy Futures in Education, 9*(6), 759-768. Retrieved January 1, 2014 from http://www.editlib.org/p/111000.

5. Elmore, Bill B., *A freshman design course using LEGO® NXT Robotics*, **Chemical Engineering Education**, Spring 2011, **45:2**, pp. 86-92.

6. Hmelo-Silver, C.E.; *Problem-based Learning: What and How Do Students Learn?;* Edu. Psych. Rev.; 16:3; Sept. 2004; pp. 235-266.

7. Thomas, J. W.; *A Review of Project-based Learning;* March, 2000; pp. 1-45; found at http://www.bobpearlman.org/BestPractices/PBL_Research.pdf

8. Randall S. Hansen (2006) Benefits and Problems With Student Teams: Suggestions for Improving Team Projects, Journal of Education for Business, 82:1, 11-19, DOI: 10.3200/JOEB.82.1.11-19. Retrieved January 4, 2014 from http://dx.doi.org/10.3200/JOEB.82.1.11-19

9. Curt J. Dommeyer; *A New Strategy for Dealing With Social Loafers on the Group Project: The Segment Manager Method;* Journal of Marketing Education; *(*2012) 34: 113; Published by:http://www.sagepublications.com; The online version of this article can be found at:DOI: 10.1177/0273475312450384

10. Strawderman, L.; B. B. Elmore; and A. Aslehi; *Exploring the Impact of First-Year Engineering Student Perceptions on Student Efficacy;* AC2009-62; Second Place—ASEE First-year Programs Division; presented at the 2009 ASEE Annual Meeting.