Session 1413

Life-long Learning Experiences and Simulating Multi-disciplinary Teamwork Experiences through Unusual Capstone Design Projects

Joseph A. Shaeiwitz
Richard Turton
West Virginia University

Introduction

There is significant consternation among engineering educators regarding the teaching of and the assessment of "an ability to function on multi-disciplinary teams," and "a recognition of the need for, and an ability to engage in life-long learning."[1] Questions commonly heard are: "Are we required to have a multi-disciplinary project experience in our curriculum?" or "How do we evaluate the ability for life-long learning?"

In this paper, a method used in the Chemical Engineering Department at West Virginia University to teach and to assess these outcomes is presented. While it is the details of the method used that will be presented, the lessons readers should learn are straightfoward. It is not necessary to implement the exact process described in this paper to teach and assess teamwork and life-long learning. If you want to teach and assess the ability for life-long learning, give students an assignment in which they have to demonstrate that they can learn new things on their own, and then assess their ability to do so. If you want students to have the ability to function on multi-disciplinary teams, give them an assignment on a large team and assess their performance in the team environment. The needs for a large team to compartmentalize assignments and for communication between compartments simulates a multi-disciplinary team. With a strong supporting argument, it is likely that this assignment would satisfy the indicated EC 2000 outcome.

Methodology

In the senior year in chemical engineering at West Virginia University, the entire class works on a large project for two semesters under the direction of a student chief engineer. If enrollments exceed 25-30, the class may be divided into two groups working on two different projects. Faculty members play roles in this exercise. One is the client, for whom the students are "hired" to complete a design project. Another is the "vice-president" of the students' company, who helps the students with technical matters. The chief engineer divides the class into groups, each headed by a group leader. The role of the chief engineer is to represent the entire team to the client and to provide leadership from the "big picture" perspective. The group leaders receive assignments from the chief engineer and are responsible for completing the work within their groups. More details of this process, including evaluation methods, are presented elsewhere.[2] Assignments are deliberately vague and open ended. The goal is to force students to define their own work statement, with input from faculty, and to learn material not normally taught in class. The exact topics students must learn are a function of the project. It is less important what they learn year to year. The goal is to make students realize that they will have to continue learning new material throughout their careers and that they have the ability to do so. Table 1 lists some

Table 1: Some Recent Large-group Projects

Project	Topics not Learned in Class
Amino Acid Production via Batch Processing	batch processing, bio-reactors
Recovery of Useful Products from Farm Animal Waste	solids handling, filtration, centrifugation, how farms work
Electricity Co-generation Using a Fuel Cell	fuel cells, pressure-swing adsorption
Carbon Dioxide Recovery and Sequestration from a Power Plant	methods for carbon dioxide recovery, geology of sequestration sites
Chemical Product Designs	product design
Production of Dimethyl Carbonate not Using Phosgene	azeotropic distillation, unique chemical reactor, green chemistry (alternative reaction path)
Recycling of Polyethylene Terephthalate	solids handling, kilns
Production of Gold	extraction of ores, mining basics, safety issues, solids handling
Tank Farm for Fuel Oils	tank design, regulations for transfers

of the more recent projects completed, with a partial list of topics not covered in class about which students had to teach themselves. A more complete description of these and other projects can be found on the Web.[3,4]

In the first semester, students perform a feasibility study. For example, in 2002-03, students were assigned to suggest opportunities for batch production. Production of amino acids was chosen; however, several other processes were investigated in sufficient detail to perform a preliminary economic analysis. These included production of a pharmaceutical (metformin HCl), production of bio-polymers (such as polylactic acid), production of celluloses (methyl cellulose, carboxymethyl cellulose, etc.), and production of dyes. In all cases, students had to use library and web-based resources to teach themselves about subjects about which they had never learned previously. They were required to work within their groups, yet have communication between groups. For example, one group suggested production of lysine and leucine, amino acids that are often used as nutrition supplements. Another group suggested aspartic acid and phenylalanine, which are the components in the sweetener Nutrasweet™. Intra-group communication, a characteristic of multi-disciplinary teams, led the two groups to recognize the similarities in production methods for all four amino acids and to suggest the possibility of a batch facility capable of producing all four amino acids.

In the second semester, students complete the design. Particularly for large processes (the fuel cell co-generation project, for example), the process must be sub-divided into component parts, assigned to different groups. However, these groups must communicate continuously, because one group's output is another group's input. We believe this to be tantamount to working on a multi-disciplinary team. Additionally, there are always required pieces of equipment that were not treated in routine undergraduate classes, particularly if solids handling is required. In order to complete the project, students must learn how to design these units on their own. Since the batch-processing project is not complete, as of the writing of this paper, the production of products from farm animal waste can be used as an example. This project was based on a research idea by one of our colleagues. Students were required to design a reactor to produce a diesel fuel additive from the waste. However, there was insufficient data to determine reasonable operating conditions. Therefore, a subset of the class (in this case, members from several groups) designed and performed experiments in the laboratory to obtain necessary information regarding the reaction kinetics. This information was used to identify a preliminary set of "best" operating conditions for the reactor. Students had to learn how to do the necessary experiments (with the aid of the faculty member) and interpret the results. In order to analyze the data, one student essentially taught himself the analysis of variance technique for the interpretation of factorial-design experiments. As an aside, this was one of the most popular aspects of the project, since it is the first time in memorable history that students obtained their own data for a design project. For other projects, students have been required to perform elementary life-cycle analyses, develop preliminary environmental-impact statements, perform HAZOPs, and suggest worst-case scenarios. These are additional examples of topics not covered (or at least not covered in depth) in class.

Assessment

The primary method for assessing students' abilities in life-long learning and multi-disciplinary teamwork is faculty observation in the course assessment. The rubric shown in Figure 1 has been developed to assess all aspects of the large-group design projects, and it includes attributes for lifelong learning and teamwork. Assessment is also done using student exit surveys, using alumni surveys, and using employer surveys.[5] It is our evaluation that students completing this design experience indeed have the requisite teamwork skills and understand the need for and have the ability for life-long learning. Since inception of the rubric, all scores have been "meets expectations" or higher. Survey results agree with this assessment.

In our student evaluation of instruction form (required, University wide), we have the ability to customize some of the questions including one user-added question. Since the two authors of this paper team-teach the design class, this year, for the first time, the user-added question for one of us addresses life-long learning, and for the other it addresses teamwork. Results of this portion of the assessment are not available as of the writing of this paper, but they will be presented at the meeting.

Discussion

It is not necessary to have a year-long experience, such as the one described here, to teach and assess life-long learning and multi-disciplinary teamwork. A smaller assignment with appropriate components would be sufficient. For example, in a capstone design class, if students have to research their own process, synthesize the their own process flow diagram, or research process alternatives, they are demonstrating the ability for life-long learning. In a laboratory class, students who have to learn theory not specifically taught in class are demonstrating the ability for life-long learning. If students are required to do a senior research project, they are

Figure 1: Rubric for Yearlong Design Project

Attribute	1-Not acceptable	2-Below expectations	3-Meets expectations	4-Exceeds expectations	Score
Design of equipment, Understand interrelationship between equipment in process					
Design of individual equipment	major errors in individual equipment design	some errors in equipment design	equipment designed correctly	unique aspects of equipment design enhance result	
Understand interrelationship between equipment on flowsheet	no understanding of equipment interrelationship	minimum understanding of equipment interrelationship	clear understanding of equipment interrelationship	exploitation of equipment interrelationship to enhance result	
Constraints/limitations of individual equipment and flowsheet understood	constraints/ limitations not understood	not all constraints/ limitations understood	constraints/ limitations clearly understood	exploitation of constraints/ limitations to enhance result	
Significance of conclusions understood	lack of understanding	gaps in understanding	clear understanding	superior understanding	
Apply chemistry, math, physics, engineering science					
Apply engineering science	inability to apply principles	weak application of principles	good application of principles	superior application of principles	
Apply chemistry	inability to apply principles	weak application of principles	good application of principles	superior application of principles	
Apply physics	inability to apply principles	weak application of principles	good application of principles	superior application of principles	
Apply mathematics	inability to apply principles	weak application of principles	good application of principles	superior application of principles	

Resolve complex problem into components	inability to recognize component problems	weak ability to recognize component problems	good ability to apply component problems	superior ability to recognize component problems	
Apply economic, physical constraints and optimization methods to obtain solution					
Show ability to use economics to drive solution to problem and focus on important parameters	economics not used to drive solution or to define key parameters	economics sparingly used to drive solution and to define key parameters	economics used to drive solution and to define key parameters	superior solution obtained by unique use of economics	▨
Define appropriate objective function	appropriate objective function not used	poorly-defined objective function used	correct objective function used	unique objective function used to obtain unique solution	▨
Define appropriate decision variables	inappropriate or no decision variables used	not all key decision variables used	correct decision variables used	unique decision variables used to obtain unique solution	▨
Correct use of optimization techniques	correct optimization techniques not used	errors in optimization methodology	correct/reasonable optimization methodology	superior optimization strategy yields unique solution	▨
Use of computer-based and other information systems	not used	omission of articles, books, etc., not available on web	uncover information from web, books, journals, etc.	uncover all pertinent information from web, books, journals, etc.	
Demonstrate ability to learn new material not taught in class	not demonstrated	reluctant to uncover and use material not taught in class	uncovered and synthesized some new material and applied to project	willingly uncovered and synthesized needed new material and applied to project	

Demonstrate ability to function in assigned role					
group member	delinquent in completing tasks	does assigned tasks and little more, often submits work late	participates in group assignments, occasionally goes beyond assigned tasks, usually submits work on time	enthusiastically participates in group assignments, routinely goes beyond assigned tasks, always submits work on time	
group leader	distributes work unevenly or does not distribute work at all, seeks no input from group, no coordination with other group leaders, does not synthesize information and is unprepared for client meetings	distributes work unevenly, seeks little input from group, coordinates poorly with other group leaders, does not synthesize information and is occasionally unprepared for client meetings	distributes work more or less evenly, usually seeks input from group, coordinates somewhat with other group leaders, synthesizes some information and is prepared for client meetings	distributes work evenly, actively seeks input from group, coordinates well with other group leaders, synthesizes information and is well prepared for client meetings	
chief engineer	unable to see big picture, does not delegate responsibilities, little or no communication with class, poor interactions with client and VP for research, will not make difficult decision when needed	difficulty seeing big picture, poor delegation of responsibilities, little communication with class, poor interactions with client and VP for research, reluctant to make difficult decision when needed	sees big picture, seeks input from group leaders, keeps class informed regarding project progress, treats group leaders and group members fairly, satisfactory interactions with client and VP for engineering, is willing to make difficult decisions regarding personnel assignments and evaluations	sees big picture clearly, consistently seeks input from group leaders, consistently keeps class informed regarding project progress, treats group leaders and group members fairly, interacts well with client and VP for engineering, is willing and able to make difficult decisions regarding personnel assignments and evaluations	

Demonstration of ethical behavior					
in dealings with peers	consistent unprofessional behavior, lying, cheating, backstabbing, disrespect for peers	generally treats peers professionally and in a forthright manner but minor occurrences of unprofessional behavior, lying, cheating, backstabbing, disrespect for peers	always treat peers professionally and in a forthright manner		
in use of information	uses work of others as own work (plagiarism)	does not always acknowledge source of information	always acknowledges source of information appropriately		
Demonstrate understanding of societal impact and need for assigned design					
inclusion of safety-related content	total ignorance of safety-related issues	reluctantly recognizes and includes relevant safety-related design issues	usually recognizes and includes relevant safety-related design issues	always recognizes, anticipates, and includes relevant safety-related design issues	
inclusion of environmentally related content	total ignorance of environmentally related issues	reluctantly recognizes and includes relevant environmentally related design issues	usually recognizes and includes relevant environmentally related design issues	always recognizes, anticipates, and includes relevant environmentally related design issues	

understanding of environmental impact of design	neither synthesizes nor demonstrates understanding of environmental impact of design	occasionally synthesizes and demonstrates understanding of environmental impact of design	usually synthesizes and demonstrates understanding of environmental impact of design	always synthesizes and demonstrates understanding of environmental impact of design	
understanding of legal issues associated with design	neither synthesizes nor demonstrates understanding of environmental impact of design	occasionally synthesizes and demonstrates understanding of legal issues associated with design	usually synthesizes and demonstrates understanding of legal issues associated with design	always synthesizes and demonstrates understanding of legal issues associated with design	

certainly demonstrating the ability for life-long learning. It is likely that most curricula already have such experiences. The only remaining issue is to assess them. The rubric in Figure 1 is one possible assessment instrument. Surveys and interviews are also possible.

The situation may be more difficult for multi-disciplinary teamwork. One idea might be to give different groups different designs that are components of a larger process, and, for a part of the project, require them to work together to synthesize the larger design. This could also be done in unit operations laboratories (There were unpublished suggestions to this effect presented at the ASEE ChE Division Summer School, Boulder, CO, 2002, in the context of injecting new life into the unit operations laboratory.).

The ultimate suggestion is that one way to demonstrate life-long learning and multi-disciplinary teamwork is to give students an assignment and assess the results. Any appropriate assignment will suffice; it does not necessarily have to be of the scope of the project described in this paper.

Conclusion

The year-long, capstone design experience in chemical engineering at West Virginia University has been presented as an example of a student experience in life-long learning and multi-disciplinary teamwork. Students have the experience described, and faculty members are able to assess the related outcomes. Suggestions have been made for other experiences that would give students similar experiences while permitting assessment of these outcomes.

Bibliography

1. "Criteria for Accrediting Engineering Programs," Accreditation Board for Engineering and Technology, http://www.abet.org.
2. Shaeiwitz, J. A., Whiting, W. B., and Velegol, D., "A Large-Group Senior Design Experience: Teaching Responsibility and Life-Long Learning," *Chemical Engineering Education,* vol. 30, no. 1, 1996, pp. 70-75.
3. http://www2.cemr.wvu.edu/~wwwche/publications/projects/index.html
4. http://www.nd.edu/~enviro/design/design.html
5. http://www.che.cemr.wvu.edu/ugrad/outcomes

JOSEPH A. SHAEIWITZ
Joseph A. Shaeiwitz received his B.S. degree from the University of Delaware and his M.S. and Ph.D. degrees from Carnegie Mellon University. His professional interests are in design, design education, and outcomes assessment. Joe is a co-author of the text *Analysis, Synthesis, and Design of Chemical Processes* (*2nd ed.*), published by Prentice Hall in 2003.

RICHARD TURTON
Richard Turton received his B.S. degree from the University of Nottingham and his M.S. and Ph.D. degrees from Oregon State University. His research interests are in fluidization and particle technology and their application to particle coating for pharmaceutical applications. Dick is a co-author of the text *Analysis, Synthesis, and Design of Chemical Processes* (*2nd ed.*), published by Prentice Hall in 2003.