INTEGRATING TEAM-BASED DESIGN ACROSS THE CURRICULUM AT A LARGE PUBLIC UNIVERSITY

Kathryn F. Trenshaw, Jerrod A. Henderson, Marina Miletic, Edmund G. Seebauer,
Ayesha S. Tillman, and Troy J. Vogel
University of Illinois at Urbana-Champaign • Urbana, IL 61801

Team-based design is a distinguishing practice in engineering and one of the principal criteria programs used for assessment of student outcomes. The importance of teaching students strong fundamental engineering principles as well as creative problem solving, conceptual understanding, adaptability, communication, and diverse leadership skills has been emphasized by broad groups of engineers and constituents for many years.[1-5]

Chemical engineering departments have contributed significantly by studying new approaches to design instruction. Specialty design courses,[6] freshman design projects and classes, [7-10] unique design competitions,[11] and smaller projects within existing courses[12-16] have enabled the evolution of design from senior-level process or plant development to a multi-year discipline-inclusive experience.

In 1992, the Chemical Engineering Department at West Virginia University (WVU) implemented design projects throughout the sophomore and junior years as preparation for the capstone process design course.[17] Three sophomore-year projects and five junior-year projects built on one another, exploring the same process or product, but posing a different challenge each time. Faculty observed students displaying creative, independent thinking and developing communication and teamwork skills.[17] This multi-year design-focused curriculum is still in place at WVU. In 1998, the Chemical Engineering Department at Clemson implemented a similar sequence of design courses throughout the curriculum using a case study approach.[18] These projects, incorporated across five semesters from sophomore to senior year, all dealt with different problems related to the same general production process taken from industry examples. Students reported they

Kathryn F. Trenshaw *is a Ph.D. candidate in the Department of Chemical & Biomolecular Engineering and member of iFoundry at the University of Illinois at Urbana-Champaign. Her Ph.D. thesis work includes developing a low-cost course conversion to increase students' intrinsic motivation to learn and investigating the climate in engineering for lesbian, gay, bisexual, and transgender (LGBT) students.*

Jerrod A. Henderson *is a lecturer in the Department of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign. In the Unit Operations Laboratory he has developed inquiry-based teaching modules for senior undergraduate students that emphasize team-building, communication, ethics, professionalism, and safety. He is committed to mentoring and interfacing with students, student organizations, and campus entities that support engineering and science education.*

Marina Miletic *served as a lecturer in the Department of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign for eight years. She taught senior Process Design and Unit Operations Laboratory and helped establish one of the nation's first week-long chemical engineering summer camps for girls. She currently works as a freelance chemical engineer and engineering education consultant.*

Edmund G. Seebauer *is the James W. Westwater Professor of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign, and served as department head during 2005-2011. His research focuses on the control of atomic-scale defect behavior in semiconductors. He presently serves as provost fellow with a goal to foster partnerships and academic programs in other countries, and to build an international focus to campus strategic planning. He is a fellow of AIChE, AAAS, AVS, and APS.*

Ayesha S. Tillman *is a doctoral candidate in educational psychology in the College of Education at the University of Illinois at Urbana-Champaign with a specialization in evaluation. Her research interests include interdisciplinary STEM education evaluation and the evaluation of large STEM educational programs. Her dissertation topic is using a values-engaged, educative evaluation approach to multi-site STEM program evaluation.*

Troy J. Vogel *is a lecturer in the Department of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign. He teaches Process Design, a senior-level course. In addition to formal teaching, he acts as the advisor for the Illinois Chapter of AIChE and AIChE's Chem-E-Car Competition. He also plays an active role in various summer camps fostering a desire to learn science and engineering in today's youth.*

learned the course material better as a result of the projects and many reported the combination of homework and design projects, as opposed to homework alone, was of great benefit to understanding course material.[18] In 1997, the Chemical Engineering Department at Worcester Polytechnic Institute also developed a "spiral" design sequence that threaded laboratory and design projects through the Material and Energy Balances, Thermodynamics, and Separations courses, combining them into one year-long course.[19-21] The faculty developed an approach that reinforces fundamental topics by revisiting and incorporating chemical engineering material in different projects with increasing difficulty at each stage. One cohort completed the new course while another followed the traditional sequence of courses as a comparison group. Faculty measured higher performance in team and individual problem solving as well as higher performance in junior- and senior-level courses with the experimental group. The laboratory and design project students also reported higher confidence levels, a more positive attitude toward chemical engineering as a discipline, and higher retention rates in the major compared to the control group students.[19-21]

Sequences of design courses culminating in capstones are slowly being developed all over the country in non-chemical engineering departments as well. Pierrakos and colleagues at James Madison University created a six-course design sequence at their School of Engineering: two sophomore design courses and a four-semester capstone design experience.[22] They found students' perceptions of ABET-based learning outcomes increased by 20 percent between freshman and junior years. At the University Park campus of Pennsylvania State University, a similar course sequence is under development.[23] The Department of Electrical Engineering started with cornerstone freshman and capstone design courses only and added a new sophomore-level design tools course, a new junior-level design process course, and a revised senior capstone design course.

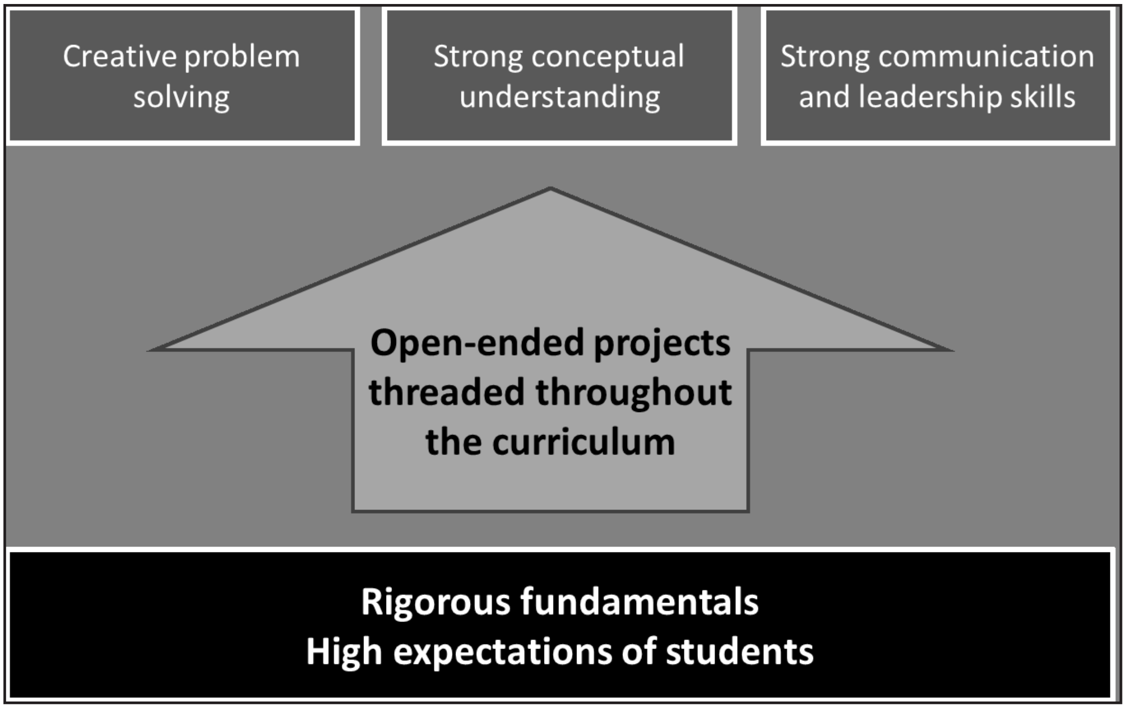

Figure 1. *Schematic of Design Across the Curriculum as a bridge to achievement of relevant outcomes.*

As we implemented team design projects across the Chemical and Biomolecular Engineering (CHBE) Department curriculum at the University of Illinois at Urbana-Champaign (UIUC), we asked the question, "How can authentic design experiences integrated into the CHBE curriculum affect student confidence in their project-related skills and perceptions of chemical engineering as a whole?" Instead of focusing on quantitative test-score improvement, which could be linked to a variety of factors, we instead assessed student perceptions of improvement in teamwork, professional, and technical skills specifically as a result of design projects implemented across a six-course sequence.

STRUCTURE AND ORGANIZATION

Design Across the Curriculum at UIUC is a CHBE-focused program in a large, public research institution. The CHBE Department has a high student-to-faculty ratio (~50:1). This program is managed at the department level and is fully integrated into the curriculum. Many projects in departments can feature an ad hoc "sprinkling" of design in several courses, but these elements are not formally integrated in the curriculum or assessed as a whole. In the context of a large public research institution, this design program is unique because it incorporates

1. *A multi-tiered organizational structure that allows students to work in groups even in large classes and receive individual attention.*
2. *A mentoring system featuring student interaction with an upperclassman for technical and professional guidance.*
3. *A program that includes all CHBE students every*

semester from freshman to senior year, not just those students who self-select to participate in a department- or campus-sponsored design project.

4. *A mixed-methods assessment of the design program as a whole, including open- and close-ended exit surveys as well as focus groups.*

Design Across the Curriculum within the CHBE Department was developed between 2008 and 2010 and first implemented Spring 2011. The primary objective was to address recurring requests from students, alumni, and advisory board members for a curriculum that features more leadership and teamwork experience, more practice with communication and presentation to wide audiences, greater experience with practical real-world challenges, incorporation of creativity and innovation within coursework, developing students' time-management and organization skills, and facilitating students' interactions with individuals of diverse skills.[24] Built on a foundation of strong technical fundamentals, design projects threaded throughout the curriculum could enable these outcomes through repeated and continued practice of creative and conceptual problem solving, communication, and development of leadership skills, as shown in Figure 1. Working in groups on real-world, open-ended projects every semester throughout their undergraduate experience gives students repeated practice in solving practical engineering challenges in teams.

The department head of CHBE and a CHBE lecturer teaching design courses at the time developed this program over two years. Its goals, organization, and structure were conceived as a means of facilitating the development of a more well-rounded graduate with team, problem-solving, leadership, and real-world project skills. Prior to implementation, this program was discussed with the faculty as a whole to ensure instructors of core courses felt there was inherent value to incorporating projects in their courses. Faculty responded favorably to implementing the program because they recognized the benefits to students of incorporating projects in their courses, while relieving them of the burden of additional time and resource costs on their part, as described below.

Incorporating design projects in courses with enrollments of more than 200 students mandates a well-planned and organized process with sufficient resources. Since most core chemical engineering classes are only offered once a year at UIUC, projects were implemented in specific courses to provide students one design experience per semester leading to their senior capstone project. These projects generally escalated in requirements and complexity with each subsequent semester, as shown in Figure 2.

To efficiently implement these projects and provide students with a meaningful level of personal attention, a hierarchical structure was developed that leverages faculty members in charge of administering the projects, a head teaching assistant (TA) in charge of team organization and general concerns, and a group of undergraduate peer mentors in charge of guiding student design teams.

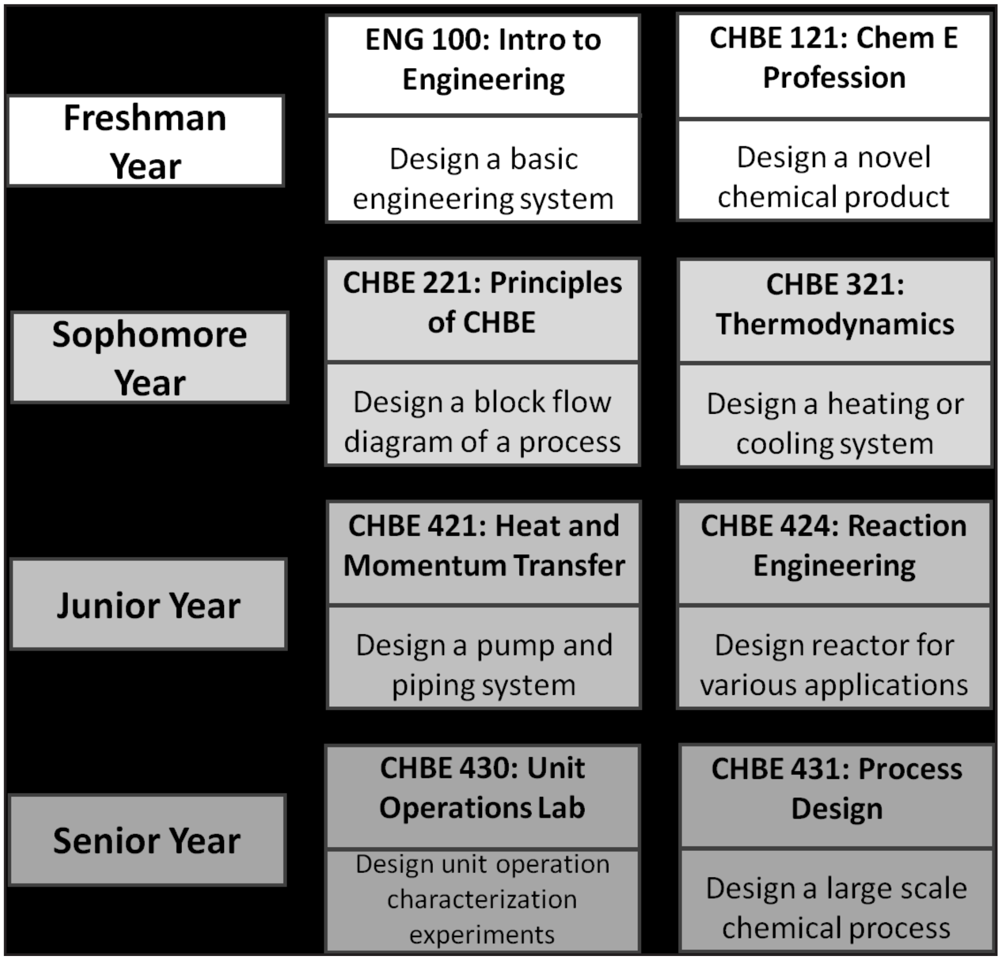

Figure 2. *Progression of design projects threaded throughout the curriculum. Projects listed are examples of a variety of options implemented any given year.*

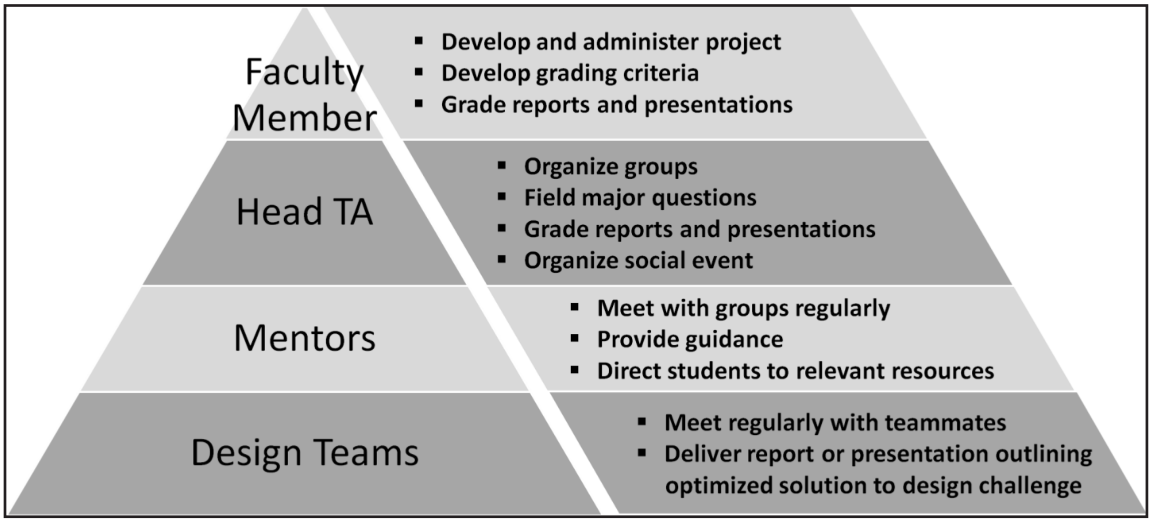

Figure 3. *Design Across the Curriculum administrative structure showing responsibilities at each level.*

Each individual plays a critical role in project implementation and facilitating student learning, as shown in Figure 3.

During this study, two lecturers served as the faculty members in charge of administering and developing design projects each semester, with each in charge of one project each semester. This administrative role could have also been assumed by tenure-system, emeritus, or adjunct faculty depending on interest and availability. The head TA position was assumed by either a senior undergraduate or graduate teaching assistant. Mentors were students who elected to earn individual study credit for serving as manager and providing technical and professional guidance to between one and seven teams. Mentors were required to have taken the course for which they managed teams in a previous year. In some cases where too few undergraduate mentors were available or interested, this role was assumed by graduate students. Initially, to incentivize students to participate in a new and untested program, mentors earned one credit hour per team. After the program's first semester, mentors earned one credit hour for every three teams. Currently, mentors earn a maximum of one hour of independent study credit per semester. Mentors were graded based on written team feedback collected at the end of each project.

Each course had between 30-50 design teams who were assigned to meet with their mentors at least once a week for the duration of each project. Any questions or conflicts that could not be addressed by the mentors were referred to the head TA. The faculty member administering the project generally did not meet with student teams, but provided project clarification as necessary. These layered roles are described visually in Figure 4.

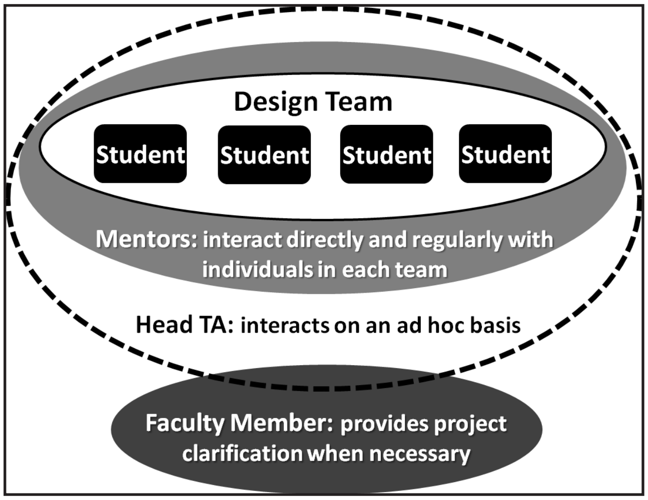

Figure 4. *Layered roles of the mentors, head TA, and faculty member in student project support.*

The size of this program necessitated a multi-tiered structure since meetings with up to 50 teams of students on a regular basis would have been burdensome for any one faculty member or small group of TAs. Since almost all questions and conflicts were resolved directly by mentors, and the head TA intervened only as needed, this structure minimized the time commitment of the faculty member in charge of the project, as shown in Figure 5.

The faculty member in charge of administering the design project was distinct from the faculty member teaching the course in all cases except CHBE 121. In other words, for almost all projects, there were no individuals who played dual roles as regular course instructor and project administrator. This arrangement relieved the course instructors and TAs from the burden of project management. Providing student teams with multiple levels of support helped ensure tenure-track faculty serving as course instructors were not diverting time from lecture or office hours to assist with the design project. However, each course instructor was given the opportunity to modify the design project statement at the beginning of the semester to best align with their course curriculum that semester.

METHODS

Design projects were integrated into five single-semester courses in the CHBE curriculum: Principles of Chemical Engineering (CHBE 221) and Momentum and Heat Transfer (CHBE 421) in the Fall 2011 semester and Chemical Engineering Profession (CHBE 121), Thermodynamics (CHBE 321), and Chemical Reaction Engineering (CHBE 424) in the Spring 2012 semester. All five courses are required in the CHBE curriculum and are taken in numerical order over five consecutive semesters. One course-specific design project with physical and economic constraints, such as size of process, energy requirements, and cost limits, was incorporated in each course and accounted for 10 percent of the final course grade. We assessed four out of the five courses over the 2011-2012 academic year. A summary of course content and accompanying design projects for these four courses can be seen in Table 1.

The majority of students were full-time, residential, and of traditional undergraduate age. During the two semesters studied, there were approximately 33% female students in each course, consistent with other large chemical engineering programs. Students came from various ethnic backgrounds in each course, with approximately 50% white, 30% Asian, and the remaining percentage either identifying another background or with no background information available. These student demographics are an accurate reflection of students in the UIUC CHBE program as a whole.

Students completed the projects in teams of three to five and stayed in the same team for the duration of the project. Students in CHBE 221 were grouped into diverse teams by their Myers-Briggs Type Indicator (MBTI) type[25] and in CHBE 321, 421, and 424 by selection based on GPA quartiles. Mentors were assigned up to three teams each. The head TA and the faculty member who developed the design project statement assigned grades for the final reports. The course instructor did not participate in grading the design projects.

Students were not given any formal design training before starting these projects. Instead, this program aimed to help students develop these skills gradually through small projects in each course, each counting for less than the value of a typical exam. This progression helped students become familiar with the design process in a relatively low-stakes environment.

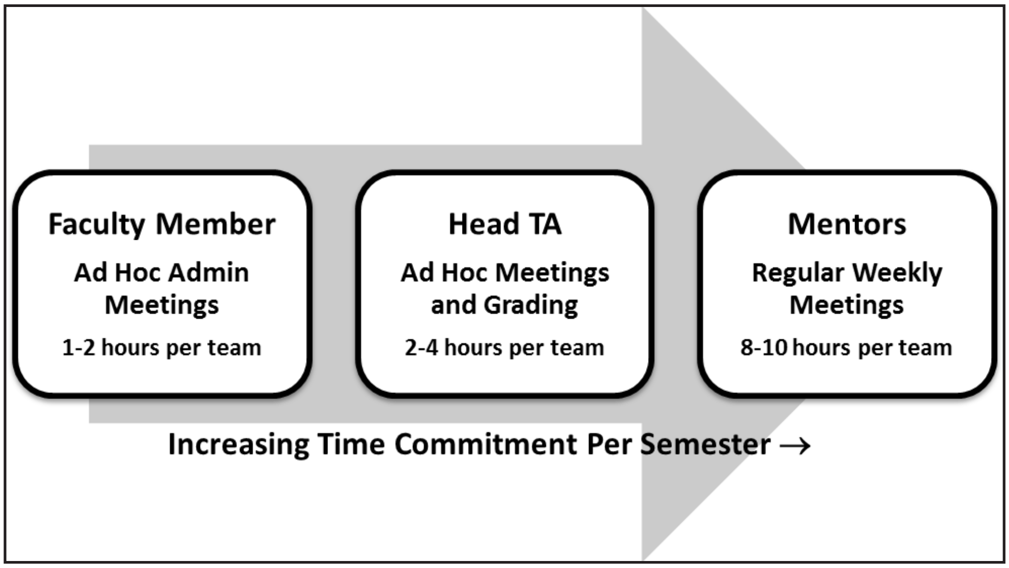

Figure 5. *Time commitment per student team for the mentors, head TA, and faculty member per semester.*

TABLE 1
Design Projects by Course Content

Course	Course Content Summary	Design Project
CHBE 221	Material and Energy Balances	Optimize the mass balance for a chemical production process to maximize profit. Deliverable: final report, some teams selected to present to BP
CHBE 321	Fundamental concepts and laws of Thermodynamics; first and second law applications to phase equilibrium and chemical equilibrium	Design a process to heat a house using an unconventional fuel source (*i.e.*, not coal or traditional fossil fuels). Deliverable: final report
CHBE 421	Introduction to Fluid Statics and Dynamics; dimensional analysis; design of flow systems; introduction to heat transfer; conduction, convection, and radiation	Design an above-ground pumping and piping system to supply cooling water to a distillation column condenser. Deliverable: final report, some teams selected to present to BP
CHBE 424	Chemical Kinetics; Chemical Reactor Design; the interrelationship between transport, thermodynamics, and chemical reaction in open and closed systems	Evaluate the feasibility of a reactor retrofit in a chemical production process. Deliverable: final report

Summaries were obtained from the UIUC course catalog entries for each course: <my.illinois.edu>.

TABLE 2
Number and Type of Questions in Exit Survey

	Fall 2011		Spring 2012	
	Closed-ended	Open-ended	Closed-ended	Open-ended
Total	**19**	**3**	**21**	**6**
• **Improvement of Teamwork Skills ($\alpha = 0.84$)**	5		5	
• **Appreciation for Engineering ($\alpha = 0.77$)**	4		4	
• **Perceived Future Benefits ($\alpha = 0.72$)**	3		3	
• **Improvement of Design Skills ($\alpha = 0.68$)**	3		3	
• **Other**	4		6	

TABLE 3
Student Response Rates to Exit Survey and Focus Groups

	Fall 2011		Spring 2012	
	CHBE 221 (N= 194)	CHBE 421 (N = 130)	CHBE 321 (N = 187)	CHBE 424 (N = 122)
Post-survey	32% (N = 63)	27% (N = 35)	24% (N = 44)	8% (N = 10)
Student Focus Groups	8 students	3 students	1 student	7 students
Mentor Focus Groups	None	None	4 Mentors	

Students were quantitatively assessed by their final reports, but neither final reports nor test scores were used to assess the efficacy of this design program since there was no control group for comparison. Having a control group for this study would arbitrarily increase or decrease the workload requirement for half the students in the course, creating an inequitable classroom environment and preventing impartial evaluation of the program. Scores from the final Process Design course were not compared to scores after the Design Across the Curriculum program was implemented because the instructors of the Process Design course had changed, resulting in the adoption of different teaching and assessment methods.

EVALUATION

To evaluate student outcomes, an integrated concurrent mixed-method research design with joint data analysis incorporating both surveys and focus groups was employed (IRB Approval #12193). Students in all four courses completed an online exit survey that gathered students' perceptions of the learning outcomes from the design projects. The surveys consisted of closed- and open-ended questions based on critical design- and team-related outcomes, as seen in Table 2. These project outcomes were written by the original CHBE Process Design Lecturer who began the program, based on ABET Engineering Accreditation Commission outcomes (c), (d), (e), (g), (h), (i), and (j).

Closed-ended questions were a mixture of 4- and 5-point Likert scale rated items. An exploratory factor analysis on the 15 post-survey questions common to both semesters was performed and Cronbach's alpha values for all 15 questions ($\alpha = 0.90$) and for each of the four individual factors were calculated. The exit survey and focus group response rates can be seen in Table 3.

A one-hour semi-structured focus group was held for each course after the design projects were completed. Students received pizza and beverages for focus group participation, but no monetary compensation. Data were analyzed from a post-positivistic perspective in which researchers attempted to minimize their biases in relation to surveys and focus groups. To this end, only authors who were uninvolved with project grading and had not interacted with students moderated focus groups such that no preconceptions about the students based on their performance were brought to the sessions. Survey analysis and theme development for open-ended questions and focus groups were carried out by the same authors who moderated focus groups with subsequent consultation from more-student-involved faculty members for clarification and peer debriefing. A thematic approach[26] was used in the analysis of the qualitative data. The authors individually coded the open-ended survey responses and focus group transcripts and then came together for consensus building and theme development. An open coding scheme based on the goals of fostering teamwork, professional, and technical skills was used as a starting point for the coding and theme-development process. When negative cases surfaced, themes were adjusted until all negative cases were accounted for. Seven major themes were identified from the qualitative data, including 1) feedback and grading, 2) project design, 3) presentation opportunities, 4) team design and experience, 5) overall experience, 6) learning outcomes, and 7) mentor experiences. Results from feedback and grading, project design, presentation opportunities, and team design and experience were used primarily for

TABLE 4

Mean responses of the exit survey question "How did the design project affect your opinion of chemical engineering as a discipline?" by course. Response was on a 5-point scale: Extremely Positive (5) - Extremely Negative (1).

Course	CHBE 221 (N = 64)	CHBE 321 (N = 44)	CHBE 421 (N = 35)	CHBE 424 (N = 10)
Mean (SD) (Out of 5)	3.29 (0.95)	3.64 (0.74)	3.39 (0.99)	3.40 (0.66)

administrative purposes. Student comments were considered representative when at least three separate students from the same course commented similarly about the same topic.

LIMITATIONS

In Spring 2012, only one student volunteered for the CHBE 321 student focus group, making it more of an interview. However, the student was asked the same questions as students in the CHBE 424 student focus group and the contributions of the interview are included below because they still represent the view of a CHBE 321 student. Because of this limitation, any quotations presented from the CHBE 321 student cannot be considered representative of at least three separate students from the same course. Additionally, the response rate from CHBE 424 students on the post-survey was considerably lower than the response rates from other courses. We hypothesize this low response rate occurred because the post-survey was administered during finals week when the vast majority of CHBE 424 students were attempting to finish their capstone design projects, pass all their final exams, and ultimately graduate. Their schedules likely did not permit them to provide even the 15 minutes required to fill out the survey in their end-of-semester rush. This limitation should be considered when comparing post-survey responses across different courses as the sample sizes and response rates vary. In future evaluations of the program, the post-survey will not be administered during finals week in the hopes of receiving a higher response rate from students.

RESULTS AND DISCUSSION

We report results for overall experience, learning outcomes, and mentor experiences below.

Overall experience

Overall, quantitative and qualitative data suggest that students perceived the design projects to be a positive learning experience. When asked the closed-ended exit survey question, "How did the design project affect your opinion of chemical engineering as a discipline?" survey respondents were slightly positive about the discipline, as shown in Table 4.

Focus group participants stated they were satisfied with the experience provided by the addition of a design project to the course, and several mentioned that after completing the project, their attitudes toward chemical engineering as a discipline improved. Representative student comments from the focus groups include:

> *"Overall, though, it was a pretty good experience because ... I [received] a really good insight into a little flavor, a little free sample, of what is [going to] be going on in the future."* - CHBE 221 student

> *"A couple of years ago I didn't want to do chemical engineering at all. I felt that I don't want to be stuck in a factory or power plant the rest of my life, but if it was something like this, you meet good people, you meet a good team and I thought it helped a lot. I have a more positive outlook in terms of what I'm going to do in the next few years."* - CHBE 421 student

Some students also compared their experience with the Fall 2011 design projects with those during the Spring 2012 semester. Students mentioned the design process was easier after having completed it before. Representative student comments from the focus groups are shown below:

> *"[The project] certainly went better than last time ... comparatively speaking, this time around it was a lot smoother."* - CHBE 321 student

> *"... for my first project, "I don't know what's going on here," but after that for the second and this semester I think that my group [was] very good ..."* - CHBE 424 student

Learning outcomes

During focus groups, students mentioned perceiving an improvement in their teamwork skills as well as their understanding of the relationship between coursework and industrial applications. A representative student comment from the focus groups is shown below:

> Interviewer: *"... what portion of the design project do you believe helped you the most for your future career ...?"*
>
> CHBE 321 student: *"... it's a toss-up between the ability to sort of effectively organize a group into a project and get people to work together toward a goal, or the ability to start from nothing and build something from scratch."*

Survey respondents reflected similar gains on the exit survey. Since open-ended questions were not prompted, students created individual responses, rather than choosing from a menu of learning outcome options. When asked the open-ended question, "List the three most important things you learned from this design experience," Fall 2011 survey respondents indicated several common outcomes, which were classified into five categories by the authors. These survey responses are shown in Figure 6 (page 146).

Survey respondents were also asked to respond to rated items about specific learning outcomes. Tables 5 and 6 (pages

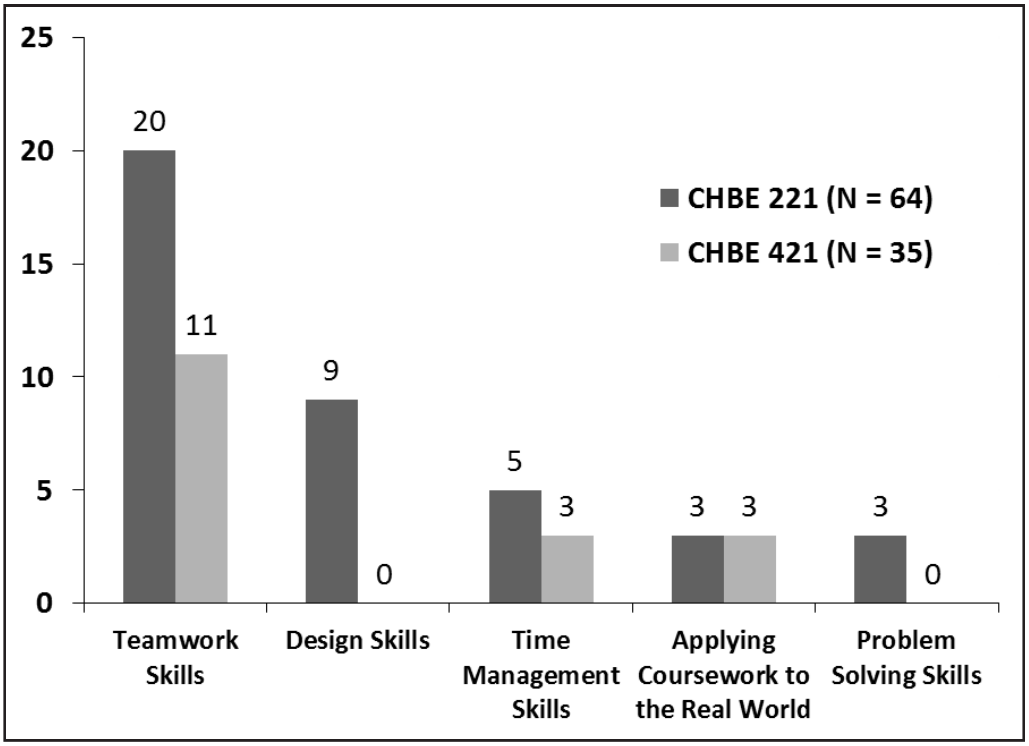

***Figure 6.** Responses by course to the post-survey question: List the three most important things you learned from this design experience.*

146 and 147) summarize the items rated highest and lowest on the exit survey, respectively. The highest- and lowest-rated items from Fall 2011 were comparable to the results in Spring 2012, with a few exceptions as noted below.

The three highest-rated learning outcomes from the exit survey were all related to a perceived improvement of teamwork skills. These closed-ended question outcomes correspond with the highest-rated outcome from the open-ended survey questions, where students suggested the same set of skills as the most important learning outcome from the project experience. This general pattern continued with the third most commonly identified outcome from the open-ended survey corresponding to the next-highest-rated outcome, applying coursework to the real world. Developing design skills was the next-highest-rated outcome for both open-ended and closed-ended exit survey questions. These data suggest reliability between both open-ended and closed-ended questions on the surveys. Three notable low scores are underlined in Table 5. The low rating associated with applying equations in class was also present in focus groups with the student reporting a disconnect between the course material and the design project.

“... in terms of actually getting a better understanding of

TABLE 5

Highest-rated learning outcomes, as measured from exit surveys.
Response was on a 4-point scale: Very useful (4) - Not at all useful (1).

Q: How would you rate this design experience with regard to…	CHBE 221 (N = 64)	CHBE 421 (N = 35)	CHBE 321 (N = 44)	CHBE 424 (N = 10)	Total (N = 153)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Improving your ability to communicate with teammates?	3.1 (0.78)	3.0 (0.84)	3.1 (0.77)	3.1 (0.83)	3.0 (0.78)
Improving your ability to work in a team?	2.8 (0.89)	2.8 (0.79)	3.1 (0.81)	2.8 (0.87)	2.9 (0.84)
Improving your ability to take a leadership role?	2.8 (0.86)	2.8 (0.91)	2.9 (0.80)	2.7 (0.46)	2.8 (0.89)
Improving your ability to compromise on decisions?	2.8 (0.90)	2.8 (0.87)	2.9 (0.90)	2.9 (0.70)	2.8 (0.89)
Learning how equations in class can be applied to make a product or piece of equipment?	2.7 (0.80)	3.2 (0.75)	2.3 (0.74)	2.9 (0.54)	2.7 (0.83)
Learning how to design a product or piece of equipment?	2.1 (0.86)	2.9 (0.67)	2.7 (0.67)	2.8 (0.40)	2.5 (0.83)
Improving your confidence that you can design a system?	2.3 (0.93)	2.7 (0.87)	2.7 (0.71)	2.8 (0.75)	2.5 (0.86)

TABLE 6
Lowest rated learning outcomes, as measured from exit surveys.
Response was on a 4-point scale: Very useful (4) - Not at all useful (1).

Q: How would you rate this design experience with regard to…	**CHBE 221 (N = 64)**	**CHBE 421 (N = 35)**	**CHBE 321 (N = 44)**	**CHBE 424 (N = 10)**	**Total (N = 153)**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Improving your report-writing skills?	2.0 (0.79)	2.3 (0.79)	2.7 (0.80)	2.5 (0.84)	**2.3 (0.83)**
Improving your ability to communicate with a mentor?	2.3 (0.90)	2.4 (0.88)	2.3 (1.0)	2.5 (0.97)	**2.3 (0.92)**
Making class more interesting?	2.5 (0.90)	2.5 (0.92)	2.3 (0.93)	2.2 (0.42)	**2.4 (0.89)**
Improving your organizational skills?	2.4 (0.89)	2.5 (0.82)	2.4 (0.97)	2.4 (0.52)	**2.4 (0.86)**
Improving your ability to be an expert in engineering?	2.4 (0.91)	2.6 (0.97)	2.5 (0.88)	2.7 (0.67)	**2.5 (0.90)**

> *thermodynamics, it didn't do a whole lot for it. The calculations were pretty simple."* - CHBE 321 student

Students in CHBE 221 gave low ratings on the development of design-related skills. Because the project focus was an open-ended mass balance problem, students assumed they were not learning design skills. However, this response did not appear in the focus groups and remains as a consideration for improving the CHBE 221 design experience.

Because there was no formal lecture, course, or training related directly to organizational skills, the relatively low ratings on the related outcomes were not surprising. Notable improvement across semesters is underlined in Table 6. Students rated the design projects as more useful in improving their report-writing skills across semesters. Similarly, students commented in focus groups about design projects "going smoother" or "being easier to conceptualize" with each iteration. These results are consistent with an increase in confidence and self-perceived skill level found by others implementing design projects throughout the curriculum.[19-21] The authors believe this indicates students felt more prepared to write the final reports with each design project they experienced in the sequence.

Mentor experiences

In Spring 2012, mentor focus groups were conducted, and additional mentor-related questions were added to the exit survey in an effort to collect additional feedback for improving project structure. While some students reported mentors who were generally not present or fulfilling their responsibility, 72% of students who responded to the Spring 2012 exit survey viewed their mentor as useful. Both mentors and students stated they understood the role and responsibility of the mentor within the team, but both groups felt mentors lacked authority.

> *"... just from being a project mentor I noticed that sometimes my job was difficult because ... I don't have authority."* - CHBE 424 student and previous mentor

Overall, mentors felt they were underprepared for their role and requested that mentor training be provided. Related to this, many mentors stated that managing many teams at once was overwhelming.

> *"We all only underwent one design project before we became mentors. We only had one class, and now we have to implement it in all these classes."* - Mentor
>
> *"[It would be useful] ... if you did an hour a week on how to lead a group, and an hour a week on what this group project is ..."* - Mentor
>
> *"Five groups is a lot."* - Mentor

If made available, mentor training should have featured elements of any teaching training program, such as guidance for meeting preparation, developing a working knowledge of available technical resources, facilitating discussion in a group setting, and answering questions while not imposing decisions or opinions. In fact, mentor training should as much as possible leverage campus- or college-wide teaching training often offered by teaching and learning centers. These programs are oftentimes the best way of leveraging expert training without burdening faculty with additional student-training obligations. Furthermore, this training should also be extended to the head TA who must be trained in organizing large numbers of groups, resolving team conflicts, and answering common project questions while not suggesting a "correct answer." If this training is not available on the campus level, then the faculty member in charge of the projects should be responsible for developing these training modules. Despite some negative comments, mentors generally conveyed a positive attitude toward student performance, admired students' dedication to the project, and felt invested in a positive student experience.

CONCLUSIONS

Implementing design projects across the curriculum can provide students with meaningful teamwork experiences even at very large schools. With sufficient resources and planning, design projects can be incorporated into almost every required course in the curriculum, giving students approximately one design experience each semester leading up to the capstone experience. For each project, a layered structure in the form of a faculty member, head TA(s), and mentor support help ensure that all students have a primary, secondary, and tertiary point of contact for guidance.

In revisiting our research question, "How can design experiences integrated into the CHBE curriculum affect student confidence in their project-related skills and perceptions of chemical engineering as a whole?" we found that students perceived improvement in a variety of project-related learning outcomes, most notably teamwork skills, bridging the gap between coursework and real-world engineering, time management, and design skills (Figure 6 and Table 5). Students generally had a positive attitude toward chemical engineering as a discipline after these design projects (Table 4) and felt more confident about future design projects after each one was completed. The focus groups and open-ended survey responses allowed students and mentors to describe their attitudes and perceptions in detail. These descriptions were supported by closed-ended survey responses that focused on affective outcomes rather than on cognitive outcomes exclusively.

In implementing a Design Across the Curriculum program in a large school, the program itself should be well organized in terms of resources and planning. Projects must balance open-ended objectives with sufficient specificity to appropriately challenge students. The percentage of the course grade allocated to the projects must be sufficient to ensure students feel that faculty members are significantly invested in the projects. Providing students with face-to-face time or presentation opportunities in front of corporate representatives is highly recommended. Training for mentors and head TAs would allow an even more efficient process if implemented correctly, as mentors could display greater authority in providing guidance and direction. In future study of the outcomes of team design experiences, we recommend investigating student motivation, attitudes, and perceptions to a greater extent than cognitive outcomes for a richer understanding of the student experience.

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