FIRST-YEAR HANDS-ON DESIGN COURSE: IMPLEMENTATION & RECEPTION

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Active and collaborative classroom environments have repeatedly been shown to improve the quality of science, technology, engineering, and mathematics (STEM) education.[1] The primary means of student learning in such environments is through guided discovery, rather than through the more passive absorption of traditional lectures. Students generally work in teams on projects that are meant to be open-ended, allowing them to develop creative skills and hone their processes for finding solutions under the professor's guidance and with the aid of peers, as opposed to traditional lecture and textbook methods that rely on more passive intake and memorization of information.

The data on the efficacy of such learning environments are rather consistent through a wide range of disciplines.[2] The most notable gains from the use of active and collaborative teaching methods have been found in students' conceptual learning[3-5] and retention of material.[6] Such methods have also been shown to improve students' self-assessment of their educational experience,[5-7] as well as aid in ABET assessment of student-learning outcomes.[8] Finally, these methods have been found to correlate with significant increases in student retention, with gains generally found in underrepresented groups.[3,5,9-11]

Established examples of successful implementation of active and collaborative teaching techniques may be found within most STEM disciplines,[12-19] and such effective teaching methods and their benefits are not new to chemical engineering (ChE) curricula either. For example, Keith, *et al*. have collected a variety of interactive teaching ideas found in the literature for ChE core courses,[20] and particularly for introductory courses.[21]

However, it is typical for ChE departments to rely on a more traditional lecture style in the freshmen and sophomore years, and save creative collaborative projects to the junior and senior years. Incoming students go into engineering, in large part, because they see the profession as inventive.[22] However, they primarily encounter lecture halls and "cookbook" lab courses early in their career. Students may experience disillusionment before a core ChE course finally makes the creativity of a ChE career relevant.

Many departments offer some sort of introduction to ChE course,[23,24] but examples of dedicated project-based ChE freshman labs are more difficult to find. We conducted a survey of 50 randomly selected undergraduate ChE programs

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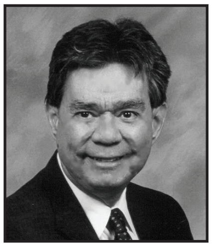

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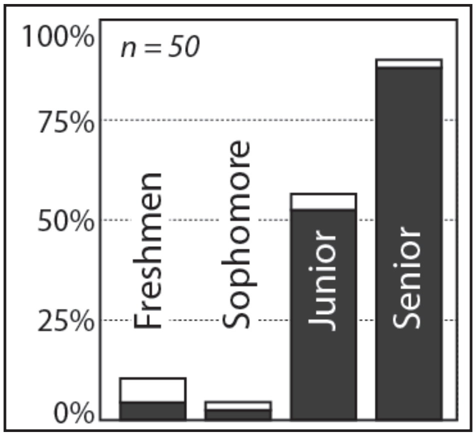


Figure 1. Percent of ChE curriculum containing an engineering lab course. White indicates a general engineering lab. Dark bars indicate a ChE-specific lab.

in the United States and found that only 10% of them offered freshmen an engineering lab experience (Figure 1). Of those labs, most (60%) were general engineering labs, not ChE-specific.[25] Several ChE freshman courses used hands-on team analysis of existing commercial products, such as copy machines, CD players, and beer.[26,27] At Mississippi State University a design lab included a liquid-level control project and used Lego® Robotix to conduct a robotic "sumo war"[28]; Keith at Michigan Tech has used similar tools to control a fluid mixing project.[29] At Northeastern University a freshman design course was implemented to specifically address environmental health and safety issues.[30] Results of this work and others suggest that there are substantial gains to be derived from a hands-on freshman design experience.

In this work, we implemented a new variant of a ChE freshman design lab and studied its effects on our students. Key goals of our work were as follows:

1. *Introduce freshmen to a variety of core ChE concepts through hands-on collaborative projects, in order to create physical anchor points of experience for core ChE theory.*
2. *Create social ties between students at different levels in the curriculum and faculty, to capitalize on the gains to be found in retention,[31,32] and learning[33] through socializing and mentoring.*
3. *Create a foundation of instructional tools from which evidence-based pedagogy may be launched throughout our curriculum.*
4. *Develop the skillset needed within our freshmen to make active and collaborative projects simpler to incorporate in future courses.*

MATERIALS & METHODS

We developed this course to incorporate a variety of recent and proven teaching innovations and chose the following as appropriate for the course.

1. Arduino Microcontrollers and Sensors: To test a broad range of design possibilities, students must be able to acquire data from a variety of sensors. Arduino Uno microcontrollers are an inexpensive ($25/board) and simple means of data acquisition[34] and allow a wide range of sensors to be easily used.[35] Using Matlab with these boards and a sensor(s), our students are able to take data from their designs and develop programming abilities. Microcontrollers have been a staple of our mechanical engineering curriculum for several years, and have been used in a variety of STEM courses.[36,37] To our knowledge they have not been used as a key component of any ChE course prior to this work.

2. Screencasts: Lectures and how-to demonstrations may be recorded and made available to students in the form of online videos using screen-capture software (*e.g.*, Camtasia Studio). Such videos have been found to be effective supplements to classroom activities and are well-received by students.[38] For this course we created a YouTube channel[39] and used screencasts to deliver lecture material outside of class, illustrate basic programming and data acquisition, demonstrate lab skills, and offer homework help.

3. Browser-Based Simulations: Inclusion of interactive online components has been shown to generally improve educational outcomes.[40] In engineering labs, students who use web simulations have been shown to have similar learning outcomes compared to those who physically use lab equipment.[41] We have developed a variety of browser-based simulations[42-44] meant to train students on simulated systems before they begin related design projects. For example, each student may be assigned a simulation for their homework with randomly generated constants and unknowns, which they are to determine. Individuals then take that experience to their team when working on related physical systems.

COURSE DETAILS

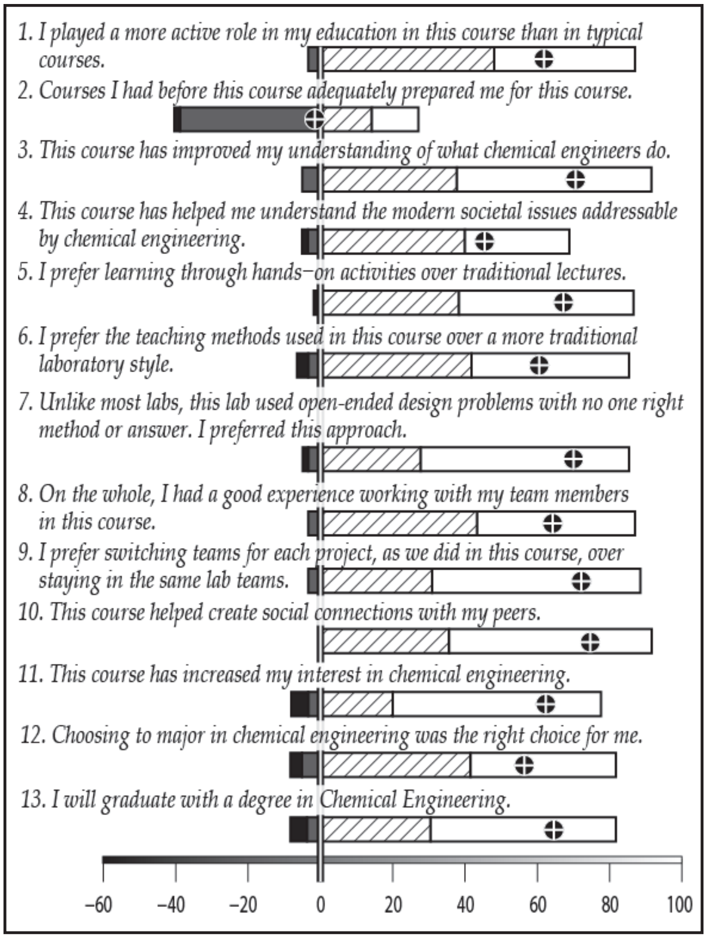
This course is a required two-credit-hour lab taught once a week for a 3-hour period, offered during the spring semester. It is conducted in two sections of approximately 35 students, with a professor and teaching assistant (TA) for each section. A $50 lab fee is used for material costs. Each teaching module begins with a lecture and discussion on an open-ended engineering problem, framing the topic in an industrial and societal context. One of the unique aspects of this course is that subsequent modules rely on the results of previous modules. For example, a spectrometer built in a previous class period is used to measure the concentration in a subsequent experiment. For each new project, student teams of three are formed randomly, while assuring no student is ever grouped with the same peer twice. Team swapping is done to maximize social connections within the cohort, assure no student remains with a dysfunctional team, and give each student a variety of teamwork experiences. For each project teams are given a set of design goals and access to wide range of materials they might use to address them. However, little to no instruction is given as to how their project should be accomplished. The professor and TA use the remainder of the class period to engage students individually. Most homework is turned in as some form of professional communication (*e.g.*, memo, standard operating procedure, slide presentation).

Teaching Modules (Weeks 2-10): After the introductory week instructing students on basic skills, such as soldering, wiring, calibration, MATLAB programming, and data analysis, students begin a series of projects. Table 1 gives a necessarily brief summary of each teaching module. Each module is primarily a goal plus a pile of miscellaneous parts and tools that may or may not be useful for that end. Students are not given detailed instructions; they are expected to find the information they need on

TABLE 1
Summary of Teaching Modules

	Topics	Summary of Lab Activities	Assignments
Basic Sensors Week 2	• Simple circuit assembly • Hydraulic analogy • Sensors • Physical measurements • Data analysis	Test the performance of a variety of sensors. 1. Choose one sensor from a varied list (temperature, pressure, humidity, CO, etc.). Sensors may be found online.[45] 2. Find sensor's datasheet, assemble an appropriate circuit, devise and execute a means to introduce a step change in its response, and record that data.	**Team:** Five-slide presentation: title, introduction, methods, results, and discussion. **Individual:** Screencast introduction to circuits. Circuit problems. Online spectrometer simulation.
Spectrometer Weeks 3 & 4	• Design cycle • Beer's Law • Calibration • Linear fits • Data analysis • Elementary reactions • Reactor types	Create a low-cost spectrometer to track a reaction in a hypothetical plant, and for use in future projects. 1. Choose a photosensor, light source, and container, similar to those described in prior work.[35] 2. Design and build a spectrometer and a flow cell. 3. Calibrate spectrometers and track a batch and CSTR alkali bleaching reaction.[35] 4. Determine the reaction rate constant.	**Team:** One-page memo with a design schematic, circuit, and costs. Memo on spectrometer's performance and calculated rate constant. **Individual:** Screencast on spectrometry. Reactor simulation.
Alginate Drug Delivery Weeks 5 & 6	• Product vs. process design • Polymers & hydrogels • Probability distributions • Mass transfer • Empirical models • Piping & instrumentation diagrams	Automate production of uniform, spherical alginate beads and quantify the rate of mass transfer from them using a model drug. 1. Create a process to use alginate and $CaCl_2$ solutions as described in Reference 46 to form at least 10 mL of beads, and separate them from the recycled $CaCl_2$ process stream, continuously without intervention. 2. Load beads with 5e-5 M Malachite Green. 3. Measure diameter and eccentricity distributions using a webcam and Matlab image processing. 4. Measure rate of "drug" release from beads using spectrometer; relate to an empirical model.[46]	**Team:** One-page memo with a piping & instrumentation diagram. Series of slides detailing their design and mass transfer results related to an empirical model. **Individual:** Fluid dynamics problems analogous to the circuit problems in Week 2. Reactor simulation.
Photobioreactor Design Weeks 7 & 10	• Biochemical engineering • Batch microbial growth phases • Growth kinetics • Fluid dynamics of mixing	Create a bench-top photobioreactor (PBR) to grow cyanobacteria as quickly as possible to supply oil for our department's biodiesel research. 1. Design and build a PBR to concentrate a stock solution of 50 cells/nL *Synechococcus Elongatus* and 400 mg/L Miracle-Gro® in city water, using 660 W fluorescent light. Example student designs may be seen in Reference 47. 2. Track microbial growth over three weeks using spectrometers.	**Team:** One-page memo with schematic of PBR with expected streamlines. Memo report on results with maximum growth rate and comparison of competing student designs. **Individual:** Online simulation of microbial growth (to be added in 2014).
Biodiesel Weeks 8 & 9	• Analytical equipment • Basic organic chemistry • Energy and fuels industry • Combustion • Process scale-up	Use a variety of analytical equipment to compare oils that may compete with our algae oil biodiesel. 1. Select a competing oil (canola, vegetable, peanut, olive, coconut, or corn) and create 50 mL of biodiesel from it using methods described in Reference 48. 2. Analyze starting oil with FTIR, UV-Vis, and refractometers. Measure density, relative viscosity, and flame temperature.	**Team:** Report on raw material costs and equipment dimensions involved in scaling up their bench-top process to 1,000 gal algae oil/day. Memo report comparing the class's pooled data to assess each oil and analytical method.

their own during class preparation, or through discussion with peers, TAs, and professors. For example, in our drug-delivery module students are tasked with creating an automatic means to produce homogenous, spherical alginate beads. They are told their process should continuously drip one fluid into another to form the beads, allow for a certain residence time, and then separate gelled beads from the process fluid, which must be recycled. There are innumerable means to accomplish such a process, and students might use a wide assortment of gas and liquid pumps, valves, tubing, and containers. Our avoidance of cookbook instruction leads to unique designs for each team, which may be comparatively assessed using product data and the design goals. Detailed information on each module may be found in associated references and by contacting the authors.



1. I played a more active role in my education in this course than in typical courses.
2. Courses I had before this course adequately prepared me for this course.
3. This course has improved my understanding of what chemical engineers do.
4. This course has helped me understand the modern societal issues addressable by chemical engineering.
5. I prefer learning through hands−on activities over traditional lectures.
6. I prefer the teaching methods used in this course over a more traditional laboratory style.
7. Unlike most labs, this lab used open-ended design problems with no one right method or answer. I preferred this approach.
8. On the whole, I had a good experience working with my team members in this course.
9. I prefer switching teams for each project, as we did in this course, over staying in the same lab teams.
10. This course helped create social connections with my peers.
11. This course has increased my interest in chemical engineering.
12. Choosing to major in chemical engineering was the right choice for me.
13. I will graduate with a degree in Chemical Engineering.

Figure 2. Student responses to survey questions. Black and gray bars indicate percentage of students responding with "Strongly disagree" and "Disagree," respectively. Diagonal lines and white indicate "Agree" and "Strongly Agree," respectively. Neutral responses are omitted. Black circles with white crosses indicate the average class response from a -100 to 100 scale for "Strongly Disagree" to "Strongly Agree." The number of students represented is 64, with 91% of students responding.

Collaborative Project with Seniors (Weeks 1, 10 - 12): At the beginning of the semester each freshman turns in a resume, which is edited by the professor and returned. In our senior projects laboratory, seniors pitch proposals for a final lab project. Projects are chosen by faculty, and a list of the selected projects is presented to the freshmen. Freshmen then rework their resume to apply to join the senior project they most desire. Senior teams receive the resumes and choose two to three freshmen to "hire," some even conducting interviews. Over three weeks, freshmen and seniors arrange to work together on the laboratory tasks needed to complete the senior's final project. At the end of the collaboration,

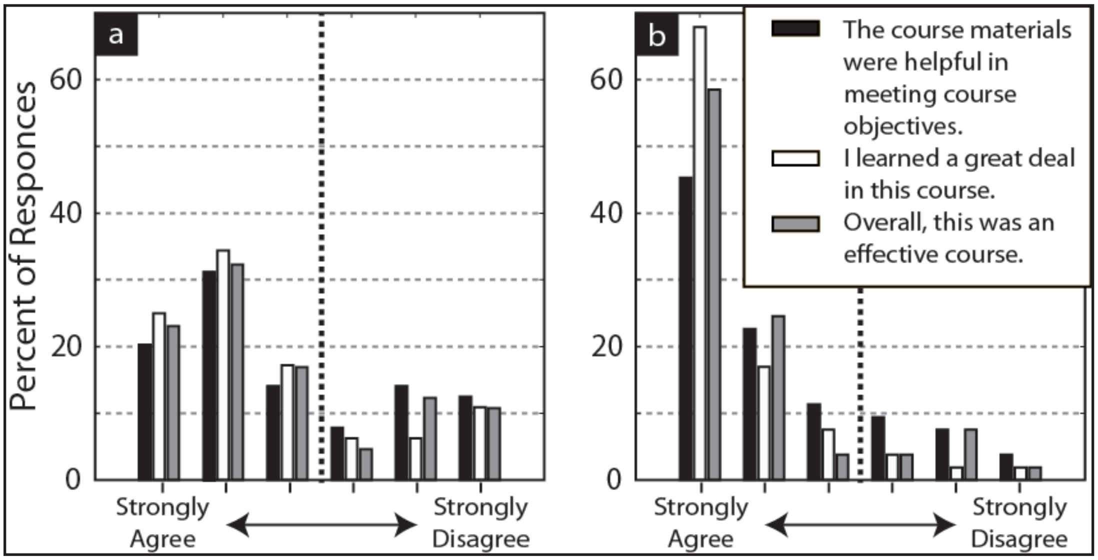


Figure 3. *Comparisons of two freshmen introduction to chemical engineering courses. Each bar graph shows student responses to three questions regarding the effectiveness of each course using a six-point Likert scale. Approximately 65 students are represented in each graph. a) Data from a traditional lecture-based introduction to chemical engineering course, given Fall semester. b) Data from an introduction to chemical engineering course using hands-on design modules, given Spring semester to the same group of freshmen.*

freshmen teams grade and are graded by their senior mentors, and they compose a memo detailing their work.

This project has several aims. Through the social connections developed between freshmen and senior students, we expected to educate freshmen on internship, research, and job opportunities, and give them a clearer view of their academic trajectory. Furthermore, we expected to develop teamwork skills within a subordinate and managerial context for freshmen and seniors, respectively—a dynamic that is common in the workplace, but not as common in academic teams.

Final Project (Weeks 12 - 16): Teams spend the final weeks of the course working on a project of their own design. Each individual student prepares a one-page project proposal—for their client, the Department of Chemical Engineering—keeping in mind the department's goals of education, service, and research. Their proposals are graded and brought to a proposal workshop in Week 13. After honing their ideas with TAs and professors, teams create a final proposal. Each team presents its project proposal to a panel of professors and TAs. This module is meant to be radically open-ended; for a project to be accepted, it must only be truly valuable work to their client and fall within budget constraints.

At Week 14, a progress report is written by the team and submitted. During the course's final exam period (Week 16), a memo report on their project is due and each team gives a 7-minute presentation on its work to the class. Resulting projects in 2013 were primarily teaching modules for outreach purposes, improvements on existing lab modules for this same design course, and manageable projects from faculty research programs.

The purpose of this final project is to exercise students' ability to identify a need and then develop and propose a solution. Furthermore, the project should boost freshmen's confidence by illustrating how the engineering and laboratory skills developed in this course have opened up a new toolbox of capabilities for solving the real-world problems.

RESULTS

Reception of the course

At the course's conclusion, students were surveyed using a standard five-level Likert scale from "strongly disagree" to "strongly agree" on a variety of statements about the course, our department, and themselves. Selected results are shown in Figure 2; many questions involved the students' perception of their abilities and are not shown. Results were also analyzed by ethnicity and gender, but no statistically significant difference from the entire population was found for any sub-group.

From Figure 2 and written comments it is apparent that students were aware they were being asked to do something very different in this class, and a sense of being underprepared was the greatest negative association students had with the course. By design, the unfamiliar teaching methods were a shock to some students, and their reaction was a matter of some concern. The general reaction might best be summed up through this student comment.

> *"I love and hate the open ended-ness of this course. I did not like it when I started, but by the end I loved it. I'm not sure how you could better prepare students for this course, and that isn't necessarily a bad thing. Whether intentional or not, it felt like jumping into a pool of freezing water—we were using real lab equipment, tackling real engineering problems, and it was a rough transition. It took me out of my comfort zone and forced me to work hard and learn a lot."*

Echoing this comment, Figure 2 also shows students felt they learned a great deal from the course. They believed their design, teamwork, laboratory, and communication skills were particularly improved (data not shown). We were concerned that reliance on manufacturing and circuitry skills might distract students from the broad survey of chemical engineering this course was intended to supply, but Questions 3-4 indicate this was not the case. We were also concerned that our more cerebral and introverted students might be put off by the hands-on team-based learning. However, over 80% of all students stated they preferred the methods used in this course over the teaching methods they had encountered in other courses, and only three students out of 64 expressed dislike for the teaching methods. Most students stated that they enjoy working in teams and that they preferred switching teams for each project as opposed to being grouped with the same peers all semester. Students nearly unanimously agreed that the course increased social connections with their peers, suggesting our goals behind team swapping were achieved.

Finally, Questions 11-13 addressed our concerns about retention effects. About 8% claimed they will not continue on in our program, compared to an approximately 60% start-to-finish attrition rate and a 36% attrition after a traditional lecture course from the previous semester. Most students lost are lost in early courses, and we would consider an 8% loss after a freshman lab to be somewhat encouraging.

Student written comments were overwhelmingly positive, with a single exception. A common theme was an appreciation for the open-ended nature of the projects, the "real-world" nature of the homework, the teaching style, and the variety of modules. Some students, while they liked the course, felt the workload was too great for the credit hours; we will be raising it to 3 credit hours and adding another lab hour. The single negative opinion focused on the open-ended style of the course, thought as undesirable—highlighting that no one teaching style could satisfy all students.

Comparison to traditional teaching methods

In the semester before this course, this same freshman cohort took a more traditional and long-standing lecture-based introductory chemical engineering course. This course introduced similar core concepts and some of the same theory: reaction kinetics, programming, mass transfer, process engineering, and so on. Figure 3 shows a comparison of pertinent questions from the standard course evaluations

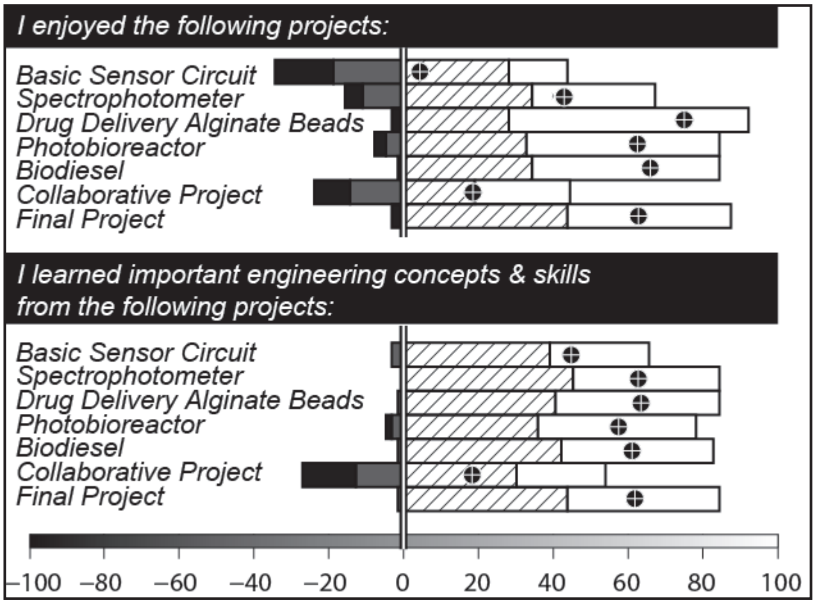


Figure 4. *Students' regard for various teaching modules. Black, gray, lined, and white bars reflect the percentage of students' response to a 5-point Likert scale for each module. Mean Likert scores from -100 to 100 are shown as black circles containing white crosses.*

for each course. While it is difficult to compare two courses for several reasons, within the same cohort, positive student assessments were substantially more frequent in the post-course evaluations of the teaching methods that used active and collaborative hands-on projects.

Comparison of modules

Figure 4 shows a comparison of students' perception of each teaching module in terms of enjoyment and learning. On average, students enjoyed each module. Notably, the first module was least enjoyed, perhaps due to the need to acclimate to the unfamiliar nature of the course and the lack of understanding of basic circuitry. However, regardless of their enjoyment, students believed they learned a great deal from nearly every module, with merely two or three students disagreeing in general. Students particularly enjoyed and felt they learned a great deal from the drug-delivery module.

Of special concern were the relatively low rankings for the collaborative project with the seniors. When groups were observed working together, this project appeared greatly successful. Seniors taught their freshmen valuable lab skills and spent downtime during experiments giving advice on courses and internships. Several freshmen were guided to and hired into internships that seniors were vacating. Furthermore, seniors were almost unanimously positive about the managerial experience they gained through the collaboration.

The causes for the relatively low ranking of the collaboration are most likely unresolved logistical hurdles. Some students had difficulty scheduling meetings with their senior teams, and in one case a senior group never contacted their freshman team. Freshmen who both strongly enjoyed and learned from the collaborative project reported spending, on average, 8 hours working with their senior supervisors, whereas students who strongly disagreed reported an average of 1.7 hours. Student Likert scale rankings of this project were proportional to time spent on the collaboration (data not shown), indicating that the experience was valuable for those who participated the most. The collaborative project delivered some important and unique returns for seniors and freshmen, and will be repeated. However, in future iterations more effort will be given to managing the logistics of this project and teaching students how to better schedule meetings through online scheduling applications.

CONCLUSIONS

Implementing a class of this nature appeared to be a gamble. Its initial execution required a significant one-time investment of department resources and planning, and the methods were unfamiliar territory for both faculty and students. However, the course has been well-received and welcomed as a permanent addition to our curriculum. From surveys, the content was clearly regarded by students as enjoyable and educational. As instructors in this course, we would personally agree on both counts. Student project reports revealed a remarkable progress in design and communication abilities over the semester. Student final projects demonstrated both creative use of newly gained skills and a confidence and comfort within the laboratory, which is often missing in even our seniors. In future work, we look forward to tracking and reporting on the long-term learning outcomes of this course for these freshmen through the remainder of our curriculum.

Currently our department is experiencing a dramatic increase in enrollment, and scale-up of this course will soon become a concern. In anticipation, we are using scalable and inexpensive projects that require minimal space. A large student-to-instructor ratio may be accommodated by the automatic grading of our online simulations, which are publicly available, and our use of screencasts for content delivery and homework help. As such, the primary bottleneck for growth is anticipated to be qualified face-to-face supervision in the lab. However, this same problem has been faced by much larger freshmen mechanical engineering design labs in our college for several years and has been successfully addressed through additional TAs per lab section, while maintaining the number of faculty. TAs address the common problems and then alert the professor to more difficult concerns. We anticipate using a similar strategy when the need arises.

Of special note, this course was also met with enthusiasm from our department's industrial advisory board (IAB). Surveys show that skills ranked as highly valued in industry, such as teamwork, hands-on know-how, and communication, are generally thought of as poorly taught by academia.[49] IAB members echoed such findings, and stated they felt this course developed the skills they most desire in new hires. They expressed a particular appreciation for the collaborative project and the development of teamwork, communication, and independent problem-solving skills. The IAB also expressed that this course may be parlayed into a significant increase in the employability of our students. Indeed, the type of experiences about which interviewers typically ask (*e.g.*, "Tell us about a time when you experienced a conflict while working in a team") are a natural consequence of such teaching methods.

One key goal of creating an introductory course using these pedagogical tools was to use the work as a means to launch such practices throughout our curriculum. To that end, we have trained our faculty on the materials used in this course, so that the skills students developed may be used throughout the curriculum. For example, all our freshmen now have the ability to assemble a simple circuit and record data from a wide range of sensors, as described in Table 1. That ability to collect and analyze real-world data, with a very modest capital investment, opens up many possible projects for other core courses. Currently, such projects are being incorporated into our process control and ChE thermodynamics courses and plans are forthcoming to develop modules for other core courses.

While our intent is not to replace traditional lectures altogether, core ChE content that is traditionally delivered in lecture form has been naturally migrating to more efficient online domains. We see the teaching methods used in this freshman lab as effective means to enhance and counterbalance both traditional lectures and online content delivery. We believe these collaborative and open-ended teaching methods have helped develop in our students an intuition for core ChE concepts and build within them skills that, although difficult to quantify, will contribute to their success.

REFERENCES

1. Kuh, G., J. Kinzie, J. Schuh, and E. Whitt, *Student Success in College*, San Francisco: John Whiley & Sons (2005)
2. Pascarella, E., and P. Terenzini, *How College Affects Students: A Third Decade of Research*, San Francisco: Jossey-Bass (2005)
3. Beichner, R., *The SCALE-UP Project: A Student-Centered Active Learning Environment for Undergraduate Programs*, National Academy of Sciences (2008)
4. Beichner, R.J., J.M. Saul, D.S. Abbott, J.J. Morse, D.L. Deardorff, R.J. Allain, S.W. Bonham, M.H. Dancy, and J.S. Risley, "The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project," *PER-Based Reform in University Physics*, vol. 1.,American Association of Physics Teachers, College Park, MD (2007)
5. Dori, Y.J., and J. Belcher, "How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts?," *J. Leaning Sci*., **14**(2), 234 (2005)
6. Dori, Y.J., E. Hult, L. Breslow, and J.W. Belcher, "How Much Have They Retained? Making Unseen Concepts Seen in a Freshman Electromagnetism Course at MIT," *J. Sci. Educ. Technol*., **16**(4), 299 (2007)
7. Oliver-Hoyo, M.T., and D. Allen, "Effects of an Active-Learning Environment: Teaching Innovations at a Research I Institution," *J. Chem. Educ*., **81**(3), 441 (2004)
8. Fisher, P., P. Zeligman, and J. Fairweather, "Self-assessed Student Learning Outcomes in an Engineering Service Course," *Int. J. Eng. Educ*., **21**(3), 446 (2005)
9. Fredericksen, E., *Minority Students and the Learning Community Experience: A Cluster Experiment*, in Conf. on Coll. Comp. and Comm. 1998 Annual Meeting, Chicago IL. ERIC#: ED423533 (1998)
10. Berry, L. Jr., Collaborative Learning: A Program for Improving the Retention of Minority Students, ERIC#: ED384323 HE028436 (1991)
11. Marra, R., K. Rodgers, and B. Bogue, "Leaving Engineering: A Multi-Year Single Institution Study," *J. Eng. Ed*., **101**(1), 6 (2012)
12. Sheppard, S., and R. Jenison, "Examples of Freshman Design Education," *Int. J. Eng. Educ*., **13**(4), 248 (1997)
13. Gaffney, J.D.H., E. Richards, M.B. Kustusch, L. Ding, and R.J. Beichner, "Scaling Up Education Reform," *J. Coll. Sci. Teach*., **37**(5), 48 (2008)
14. Beichner, R., Y.J. Dori, and J. Belcher, *New Physics Teaching and Assessment: Laboratory and Technology Enhanced Active Learning*, Washington, DC: National Science Teachers Association (2006)
15. Beichner, R., "Instructional Technology Research and Development in a U.S. Physics Education Group," *Eur. J. Eng. Educ*., **31**(4), 383 (2006)
16. Benson, L., S. Biggers, W. Moss, M. Ohland, M. Orr, and S. Schiff, "Adapting and Implementing the Scale-Up Approach in Statistics, Dynamics, and Multivariate Calculus," *Proceedings of the Am. Soc. Eng. Educ*., 2007 Annual Conference and Exposition, Honolulu (2007)
17. Carlson, L., and J.F. Sullivan, "Hands-on Engineering: Learning By Doing in the Integrated Teaching and Learning Program," *Int. J. Eng. Educ*., **15**(1), 20 (1999)
18. Aglan, H.A., and F. Ali, "Hands-On Experiences: An Integral Part of Engineering Curriculum Reform," *J. Eng. Educ*., **85**(4), 327 (1996)
19. Beichner, R., "SCALE-UP Site," Available: <http://scaleup.ncsu.edu/> Accessed 13-April-2014
20. Keith, J.M., D.L. Silverstein, and D.P. Visco, "Ideas to Consider for Chemical Engineering Educators Teaching a New 'Old' Course: Freshman and Sophomore Level Courses," *Chem. Eng. Ed*., **43**(3), 207 (2009)
21. Keith, J.M., D.L. Silverstein, D.P. Visco, and L.G. Bullard, "Ideas to Consider for New Chemical Engineering Educators: Part 2 (Courses Offered Later in the Curriculum)," *Chem. Eng. Ed*., **44**(4), 306 (2010)
22. Intel, "Survey of Teens' Perceptions of Engineering," (2011) <http://newsroom.intel.com/servlet/JiveServlet/download/35-7266/Intel-Engineering-Survey.com> Last accessed 14-April-2014
23. Solen, K., and J. Harb, "An Introductory ChE Course for First-Year Students," *Chem. Eng. Ed*., **32**(2), 52 (1998)
24. Miller, W.M., and M.A. Petrich, "A Novel Freshman Class to Introduce ChE Concepts and Opportunities," *Chem. Eng. Ed*., **25**(1), 134 (1991)
25. Hall, D., H. Hegab, and J. Nelson, *Living WITH the Lab—A Freshman Curriculum to Boost Hands-on Learning, Student Confidence, and Innovation*, FIE, Saratoga Springs, NY, pp. 8–13 (2008)
26. Beaudoin, D.L., and D.F. Ollis, "A Product and Process Engineering Laboratory for Freshmen," *J. Eng. Educ*., **84**(3), 279 (1995)
27. Farrell, S., K. Jahan, R.P. Hesketh, J.A. Newell, and M.J. Savelski, *Session Introducing Freshman Engineering Students to Chemical Product Design*, iCEER, Manchester, England (2002)

28. Elmore, B.,"A Freshman Design Course Using Lego NXT Robotics," *Chem. Eng. Ed.*, **45**(2), 86 (2011)
29. Keith, J.M., "Learning 'Outside the Toy Box'," in *Proceedings* of the 2002 ASEE Conference & Exposition (2002)
30. Willey, R., and J. Price, "Freshman Design Projects in the Environmental Health and Safety Department," *Chem. Eng. Ed.*, **32**(1), 58 (1998)
31. Bean, J.P., "Interaction Effects Based on Class Level in an Explanatory Model of College Student Dropout Syndrome," *Am. Educ. Res. J.*, **22**(1), 35 (1985)
32. Mangold, W.D., L.G. Bean, D.J. Adams, W.A. Schwab, and S.M. Lynch, "Who Goes Who Stays: An Assessment of the Effect of a Freshman Mentoring and Unit Registration Program on College Persistence," *J. Coll. Student Retent. Res. Theory Pract.*, **4**(2), 95 (2003)
33. Eyler, J., D. Giles, C. Stenson, and C. Gray, *At a Glance: What We Know about the Effects of Service-Learning on College Students, Faculty, Institutions and Communities 1993-2000*, 3rd Ed. Nashville: Vanderbuilt University (2001)
34. "Arduino," [Online]. Available: <http://www.arduino.cc/>
35. Butterfield, A., and C. Young, "An Effective and Economical Photometer for Classroom Demonstrations and Laboratory Use," *Chem. Eng. Ed.*, **46**(3), 152 (2012)
36. "A first Course in Computer Programming For Mechanical Engineers," [Online]. Available: <http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5552091&url=http://ieeexplore.ieee.org/xp ls/abs_all.jsp?arnumber=5552091>
37. Galeriu, C., "An Arduino-Controlled Photogate," *Phys. Teach.*, **51**(3), 156 (2013)
38. Falconer, J., J. DeGrazia, J.W. Medlin, and M. Holmberg, "Using Screencasts in ChE Courses," *Chem. Eng. Ed.*, **43**(4), 286 (2009)
39. Butterfield, A., "Screencast YouTube Channel," Available: <http://www.youtube.com/user/AEButterfield> [Accessed: 18-Sep-2013]
40. Jones, K., "Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies," U.S. Department of Education, Office of Planning, Evaluation, and Policy Development Policy and Program Studies Service (2009)
41. Nickersona, J.V., J.E. Corterb, S.K. Eschea, and C. Chassapisa, "A Model For Evaluating the Effectiveness of Remote Engineering Laboratories and Simulations in Education," *Comput. Educ.*, **49**(3), 708 (2007)
42. Butterfield, A., "Online Teaching Material," Available: <http://www.che.utah.edu/~tony/OTM/> (2011)
43. Butterfield, A., "JavaScript Statistical Functions," Available: <http://www.che.utah.edu/~tony/OTM/Statistics/all_funcs.php> (2010)
44. Butterfield, A., "Browser-Based Simulations for the Illustration of Chemical Engineering Concepts," in AICHE Annual Meeting, Minneapolis, MN (2011)
45. Butterfield, A., "Sensors, Anthony (Tony) Butterfield, Department of Chemical Engineering, University of Utah," Available: <http://www.che.utah.edu/~tony/Courses/CHEN_1705/sensors.php> [Accessed: 10-Feb-2013]
46. Farrell, S., and J. Vernengo, "A Controlled Drug-Delivery Experiment Using Alginate Beads," *Chem. Eng. Ed.*, **46**(2), 97 (2012)
47. Butterfield, A., "Photbioreactors from ChEn 1705, U of U," Available: <http://www .youtube.com/watch?v=GScKdnn1lho&list=UUf3alYXUCXW4mBJOETDoFUg> [Accessed: 18-Sep-2013]
48. Tickell, J., *From the Fryer to the Fuel Tank*, 3rd Ed., Tickell Engineering Consulting, Hollywood, CA (2003)
49. Becker, F.S.,"Why Don't Young People Want to Become Engineers? Rational Reasons For Disappointing Decisions," *Eur. J. Eng. Educ.*, **35**(4), 349 (2010) ❐