AC 2010-4: IDEAS TO CONSIDER FOR NEW CHEMICAL ENGINEERING EDUCATORS: SENIOR DESIGN

Lisa Bullard, North Carolina State University

Dr. Lisa G. Bullard is a Teaching Associate Professor and Director of Undergraduate Studies in the Department of Chemical and Biomolecular Engineering at North Carolina State University. She served in engineering and management positions within Eastman Chemical Co. from 1991-2000. A faculty member at NCSU since 2000, Dr. Bullard was named an Alumni Distinguished Undergraduate Professor at NCSU and was awarded the Outstanding New Teacher Award by the Southeastern Section of ASEE, the NCSU Alumni Outstanding Teaching Award, the COE George H. Blessis Outstanding Undergraduate Advisor Award, and the NCSU Faculty Advisor Award.

Ideas to Consider for New Chemical Engineering Educators: Senior Design

Abstract

Teaching the senior or "capstone" design course can be intimidating to new faculty members since the course is typically more open ended and project-based compared to other traditional core courses. Faculty with backgrounds in chemistry or physics who join a chemical engineering department may have never taken such a course themselves. In many departments, the course was traditionally taught by a retired industrial practitioner who had a good idea of the types of deliverables that were representative of what students would encounter in the workplace, but this may not be the case today. In addition, the advent of process simulators in the 1970's and 1980's had a huge impact on the way that senior design is currently taught. This paper summarizes the author's selection of the most effective, innovative approaches for the capstone design course reported recently in the literature or discussed at previous conferences. The challenges associated with teaching senior design, and approaches successfully applied to address these challenges, are also described.

Introduction

The senior design course in chemical engineering typically includes both traditional lecture content as well as a capstone project. Academic content typically includes flowsheet synthesis and development, process simulation, process economics, and equipment design/heuristics. Depending on the background of the instructor and whether the course is one or two semesters, a laundry list of additional topics might include sustainability and "green design" concepts,[1] process safety,[2] Good Manufacturing Practice, Six Sigma,[3] optimization,[4] selecting materials of construction, reading P&ID's, heat exchanger network or reactor network synthesis, environmental regulations, engineering ethics, batch scheduling, and product design.[5] Senior design is also the last opportunity to reinforce "soft skills" such as teamwork[6,7] and communication.[8, 9]

Course Organization and Structure

Whether the course is one semester or two will significantly impact how the course is organized, the content that can be covered, and the scope of the design project. According to a recent survey conducted by John Wiley based on a response from 50 departments, US chemical engineering departments are split down the middle – half teach one design course, and half teach a two-semester design sequence.[10]

Instructors have several challenges related to the structure and organization of the course. Departments who teach one design course must be very selective and choose which content is most important for its graduates. Design projects for a one-semester offering might be best structured as multiple smaller problems that reinforce the course content being covered. Departments who teach two design courses have more flexibility to cover additional specialized content, present information on product design as well as process design, invite guest speakers, and pose design projects that stretch over an entire year.

Coming up with new projects each year can be a challenge for instructors. Starting early is important since it may take some time to define prospective projects and mentors. In addition to gleaning ideas from in the literature (discussed below), solicit departmental faculty at the end of the spring semester or in the summer to generate some ideas. Contact enrolled students early in the summer and invite them to define their own project subject to some constraints on what the project should include. If your campus has an Engineering Entrepreneurship class, partner with them to include your students.[11, 12]

Industrial partners, especially if the department is located near industry or research organizations, can serve as sources of design projects and mentors. The local AIChE section could be a good resource for local practitioners who would be willing to participate. Industrial alumni who have been through the course can be excellent mentors because they are familiar with the deliverables required. In addition, industrial advisory boards may be helpful in identifying key skills expected for new employees, which may help define course content.

Additional project advisors may be needed depending on the class size and the instructor's background. Some departments enlist all faculty to propose and sponsor one design project each year. Other sources of mentors include faculty in other related departments (e.g. Materials Science, Food Science, Environmental Engineering, or Computer Science); this is especially effective if the students are double majors in that department.

If students are working on projects that require experimental work or small scale construction, funding can be an issue. Most departments have funds available for laboratory equipment and supplies, but funding levels for design must be considered when proposing and defining the scope of projects. Some departments ask companies to sponsor projects for a flat fee (e.g. $5000) or the cost of materials. Industrial advisory board members/companies or alumni may be additional sources for senior design funds.

Depending on the deliverables, the learning outcomes, and the number of mentors involved, assessment can be a challenge. Approaches to this issue are discussed by Baker et al., [13] Rogge et al., [14] and Davis et al. [15] As an example, rubrics for grading written reports, oral presentations, and posters are included in Appendix A.

Examples of Design Projects:

- The text by Turton et al.[16] contains six complete senior design projects in addition to the extensive list of project on their web site.[17] Shaeiwitz and Turton[18] describe two examples of novel capstone design projects: an ice cream manufacturing process and the design of a transdermal drug delivery patch. In addition, they have developed additional product design projects.[19]

- The text by Peters et al.[20] includes problem descriptions for five major projects, five minor design problems, and seven practice session problems
- Bullard et al.[21] provide three web-based case studies in the area of biomanufacturing for the production of co-protein, citric acid, and ammonia. Supporting materials have been developed for each case study, including a problem statement, an exemplary solution, and a summary of the difficulties and typical errors that might be encountered.
- Weiss and Castaldi[22] described a tire gasification senior design project that integrates laboratory experiments and computer simulation.
- Benyahia[23] outlines a project involving vinyl chloride monomer (VCM), emphasizing its compliance with ABET 2000 criteria.
- Hernandez et al.[24] present a biodiesel design project which highlights the potential contributions of chemical engineering to areas such as new energy sources, global warming, and environmental sustainability.
- While the text by Allen and Shonnard[25] does not have design problems per se, it does discuss concepts such as green chemistry approaches, flowsheet analysis for pollution prevention, and life cycle analysis that could provide the basis for or be integrated into an existing design project.

Examples of Ideas for Course Content and Structure

In addition to the comprehensive final written report, consider having a poster session to which you invite the students' parents, the Industrial Advisory Board members, and current junior students. Starting off with a 2-minute (or longer, depending on the number of projects) summary of each project and then adjourning to a 60-90 minute poster session can be an effective way of having students present their work and creates a celebratory environment instead of the high stakes formal presentation. Parent response to this type of event is typically very positive; it may be the first time they've been invited to participate in an event at the university involving their student. This also gives rising seniors an opportunity to see what is required for a senior capstone project. Giving awards for "best in show" recognizes those students who make exceptional effort and helps rising seniors see where the bar is set. If there are concerns that the absence of a formal project review will de-emphasize quality and the correctness of the solution, these can be addressed by designating faculty or industrial advisors who serve as technical judges and visit each poster to rigorously quiz the team members.

As part of the class activities for the capstone course, consider inviting guest speakers who can help students understand the application of what they are learning in the profession. Depending on the focus of the course, this could include both "traditional" speakers who directly address topics related to process design and operation, as well as engineering graduates who have had non-traditional careers (medicine, law, pharmacy, business, teaching, or entrepreneurship). Financial planning, business and electronic etiquette, and professional dress are issues which students will soon face. Alumni panels on "Making the Transition from Student to Employee", "Changing Jobs", and "Graduate School" can be a very effective way to address these issues.

Organizations such as AIChE,[26] the World Congress of Chemical Engineering,[27] and NASA[28] sponsor annual design competitions. Kundu and Fowler[29] discuss the use of engineering design competitions to engage students. Often these involve the use of multidisciplinary teams, which is discussed by Redekopp.[30]

Web Resources that Help Teach Auxiliary Skills:

- Cadwell et al. [31] feature a series of short on-line videos on "Topics in Engineering Design" which include communication in design, design considerations, the design process, and patents and literature.
- The On-Line Ethics Center at the National Academy of Engineering,[32] the Markkula Center for Applied Ethics,[33] and the Center for the Study of Ethics in Society[34] have web sites with case studies and other materials for teaching engineering ethics.
- Process safety modules are available through the Safety and Chemical Engineering Education (SAChE) program.[35]
- The Thomas Register[36] is a useful database for equipment vendors.
- The EPA makes available exposure assessment tools and models.[37]

Software Resources:

- Process simulators typically used in senior design include Aspen Dynamics, Aspen HYSYS, Aspen Plus, Batch Plus, CHEMCAD, PRO/II, SuperPro Designer, and UNISIM.
- The Aspen academic suite has several new modules. Aspen Process Economic Analyzer (formerly Icarus Process Evaluator) can be used for interactive equipment sizing as well as estimation of purchase costs and total investment. The package now includes modules for adsorption and batch distillation.[38]
- The text and web site by Seider et al.[39] include self-study examples and multimedia instruction, focusing on Aspen Plus and HYSYS.
- The text by Turton et al.[40] contains a CD-ROM with the latest version of CAPCOST, a tool for evaluating fixed capital investment, full process economics, and profitability—now expanded with cost data for conveyors, crystallizers, dryers, dust collectors, filters, mixers, reactors, and screens. It also contains the HENSAD tool for constructing temperature interval, cascade, and temperature enthalpy diagrams; estimating optimal approach temperatures; and designing heat exchanger networks.

Trouble Spots for Students

Although most students have worked in groups during unit operations lab or in homework groups, senior design is by far the biggest group project that many of them have tackled. Instructors should require design teams to define team expectations, roles, and responsibilities early in the semester. Sauer and Arce describe one process of team selection and defining roles and responsibilities based on a functional approach.[41] Providing instruction or resources on the phases of team performance, personality types[42], and learning styles[43, 44] can alleviate potential problems. Administering a peer evaluation tool is essential since much of the course grade will depend on the group project. CATME[45, 46] is an easy-to-use online tool that collects and analyzes self and peer evaluations of team members' contributions. Ideally some type of peer evaluation instrument is administered with each major deliverable, and team members receive feedback on their individual performance compared to the group average. Any low performing students should be identified by the instructor, and the team should meet with the instructor to discuss the issue so that it can be addressed early. Instructors might also consider a mechanism that reflects in individual contribution; for example, students could be required to keep a design notebook[47] or submit their individual written contributions. This can be helpful if there is dissent within the team about an individual's contribution.

The senior design report is likely the most formal and the longest document that students will produce. Even if students have taken a technical writing course, many are overwhelmed and do not feel confident about structure, format, and citation details. The instructor should provide instruction or resources in technical writing, oral presentations, and how/when to cite.[48, 49] Providing students with exemplary documents from a previous year can be very helpful in demonstrating what you expect. Some campuses have Writing and Speaking Centers on campus or in-house technical writing consultants who can assist by providing resources, giving a class lecture, or even reviewing student work. Allowing groups to submit a draft to the instructor a week in advance for a review can identify major problems while still allowing time for correction.

Student procrastination: The combination of senioritis and procrastination can result in students trying to cram in months of works into weeks or days. Instructors can help students pace themselves by structuring the project into deliverables that are spread over the one or two semesters. For example, in a two semester sequence in which the projects are assigned in October, students could produce a literature review/technical background in November, a status report in February, an oral presentation in March, and the final report and poster in April. Design teams should submit a project schedule and work plan early on as one of the deliverables. Some instructors require students to produce progress reports in memo form periodically during the duration of the project. Finally, depending on the size of the class, the instructor and/or additional project mentors could meet with each team or each project manager regularly throughout the semester to hold them accountable.

Conclusions

ABET specifically addresses the requirement for design in Criterion 3(c): "Student must…attain the ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." [50] However, an instructor could easily argue that a capstone design class could meet all eleven ABET Program Outcomes (a) – (k), depending on the structure and focus of the course. While the demands of such a course can be overwhelming to both the instructor and to the students, judicious choices by the instructor regarding the project topics, support resources and the content and timing of student deliverables can reduce the ambiguity and provide helpful support to students.

References

(1) Foster, J. and A. Heeney, "The Engineering Science Praxis Sequence: Challenges and Opportunities When Integrating Sustainable Development into the Engineering Classroom," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).

(2) Seay, J.R and M.R. Eden, "Incorporating Risk Assessment and Inherently Safer Design Practices into Chemical Engineering Education," *Chemical Engineering Education,* 42(3), 141-146 (Summer 2008).

(3) Dai, LL., " Incorporating Six Sigma Methodology Training into Chemical Engineering Education," Chemical Engineering Education, 41(1), 53-56 (Winter 2007).

(4) Biegler, L.T., I.E. Grossman, and A.W. Westerberg, *Systematic Methods of Chemical Process Design*, Prentice Hall International Series in the Physical and Chemical Engineering Sciences, 1997.

(5) Cussler, E.L. and G.D. Moggridge, Chemical Product Design, Cambridge University Press, 2001.

(6) Newell, J., K. Dahm, R. Harvey, and H. Newell, "Developing Metacognitive Engineering Teams, Chemical Engineering Education, 38(4) (Fall 2004).

(7) Lumsdaine, E., J. Loukus, J. Dreyer, S. Chenoweth, and M. Lumsdaine, "Forming and Managing Project Teams in a Large Capstone Design Course," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).

(8) Dannels, D.P., C. Anson, L.G. Bullard, and S.W. Peretti, "Challenges in Learning Communication Skills in Chemical Engineering," Communication Education, 52, (2003).

(9) Suraishkumar, G.K., "Improving Coherence in Technical Writing," *Chemical Engineering Education,* 38(2) (Spring 2004).

(10) Seider, W.D., J.D. Seader, D.R. Lewin, and S. Widagdo, *Product and Process Design Principles: Synthesis, Analysis, and Evaluation,* John Wiley, 3rd Edition (2009).

(11) Ohland, M.W., S.A. Frillman, G. Zhang, C.E. Brawner, and T.K. Miller, "The Effect of an Entrepreneurship Program on GPA and Retention," *Journal of Engineering Education,* 93(4), 193-201, October 2004.

(12) Deneen, S., "Seize the Day," *Success,* 57, Sept. 2009.

(13) Baker, J., M. Yoder, B. Black, R. Throne, and W. Kline, "Scorecards: Tracking Progress in Senior Design Project Courses," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).

(14) Rogge, R., K.C. Dee, and G. Livesay, "Development of an Evaluation for Assessing Student Practices, Independence, and Responsibility in Design Courses, "*Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).

(15) Davis, D., P. Thompson, and S. Beyerlein, "Web-Based Assessment of Capstone Engineering Design," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).

(16) Turton, R., R.C. Bailie, W.B. Whitning, and J.A. Shaeiwitz, *Analysis, Synthesis and Design of Chemical Processes*, Prentice Hall International Series in the Physical and Chemical Engineering Sciences, 3rd Edition (2009).

(17) Design Projects. *West Virginia Department of Chemical Engineering.* http://www.che.cemr.wvu.edu/publications/projects/index.php

(18) Shaeiwitz, J.A. and T. Turton, "Design Projects of the Future," Chemical Engineering Education, 40(2), (Spring 2006).

(19) Shaeiwitz, J.A. and T. Turton, "Chemical Product Design," Chemical Engineering Education, 30(4), (Fall 2001).

(20) Peters, M.S., K.D. Timmerhaus, and R.E. West *Plant Design and Economics for Chemical Engineers,* McGraw Hill, 5th Edition (2003).

(21) Bullard, L.G., P.K. Niehues, S.W. Peretti, and S.H. White, "Web-based Delivery of Chemical Engineering Design Projects," *Chemical Engineering Education*, 39(3), 194-199 (Summer 2005).

(22) Weiss, B. and M.J. Castaldi, "A Tire Gasification Senior Design Project that Integrates Laboratory Experiments and Computer Simulation," *Chemical Engineering Education,* 40(3), 203-210 (Summer 2006).

(23) Benyahia, F., "VCM Process Design: An ABET 2000 Fully Compliant Project," Chemical Engineering Education, 39(1), 62-67 (Winter 2005).

(24) Hernandez, R., T. Jeffreys, A. Marwaha, and M. Thomas, "Plant Design Project: Biodiesel Production Using Acid-Catalyzed Transesterification of Yellow Grease," Chemical Engineering Education, 40(3), 215-224 (Summer 2006).
(25) Allen, D.T. and D.R. Shonnard, *Green Engineering: Environmentally Conscious Design of Chemical Processes*, Prentice Hall (2001).
(26) AIChE. *National Student Design Competition.* http://www.aiche.org/Students/Awards/NationalStudentDesignIndividual.aspx
(27) World Congress of Chemical Engineering. *SNC-Lavelin Plant Design Competition.* http://www.wcce8.org/prog_student_snclav.html
(28) NASA. *Microgravity University.* http://microgravityuniversity.jsc.nasa.gov/
(29) Kundu, S. and M.W. Fowler, "Use of Engineering Design Competitions," *Chemical Engineering Education,* 43(2), 131-136 (Spring 2009).
(30) Redekopp, M., C. Raghavendra, A. Weber, G. Ragusa, and T. Wilbur, "A Fully Interdisciplinary Approach to Capstone Design Courses," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).
(31) Cadwell, K., G. Zenner, N. Chesler, and W. Crone, "Developing Undergraduate Students' Design Skills Using On-Line Video Modules and Active-Learning Exercises," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).
(32) National Academy of Engineering. *On-Line Ethics Center.* http://www.onlineethics.org/
(33) Markkula Center for Applied Ethics. *Ethical Decision Making.* http://www.scu.edu/ethics/practicing/decision/
(34) Center for the Study of Ethics in Society. *Teaching Engineering Ethics: A Case Study Approach.* http://ethics.tamu.edu/pritchar/an-intro.htm
(35) Center for Chemical Process Safety. *Safety and Chemical Engineering Education Program.* http://sache.org/index.asp
(36) Thomas Net. *Thomas Register.* http://www4.thomasregister.com
(37) Environmental Protection Agency. *Exposure Assessment Tools and Models.* http://www.epa.gov/oppt/exposure/pubs/episuitedl.htm.
(38) University Program. *Aspen Tech.* http://www.aspentech.com/corporate/university/products.cfm
(39) Seider, W.D., J.D. Seader, D.R. Lewin, and S. Widagdo, *Product and Process Design Principles: Synthesis, Analysis, and Evaluation,* John Wiley, 3rd Edition (2009).
(40) Turton, R., R.C. Bailie, W.B. Whitning, and J.A. Shaeiwitz, *Analysis, Synthesis and Design of Chemical Processes*, Prentice Hall International Series in the Physical and Chemical Engineering Sciences, 3rd Edition (2009).
(41) Sauer, S. and P.E. Arce, "Team Member Selection: A Functional-Based Approach," *Proceedings of the 2004 Annual Conference & Exposition,* ASEE (2004).
(42) Myers and Briggs Foundation. *My MBTI Personality Type.* http://www.myersbriggs.org/
(43) Felder, R. *Index of Learning Styles.* http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html.
(44) Felder, R. *Index of Learning Styles.* http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html.
(45) Ohland, M.W., M.L. Loughry, R.L. Carter, L.G. Bullard, R.M. Felder, C.J. Finelli, R.A. Layton, and D.G. Schmucker, "The Comprehensive Assessment of Team Member Effectiveness: A New Peer Evaluation Instrument," *Proceedings of the 2006 Annual Conference & Exposition,* ASEE (2006).
(46) *Comprehensive Assessment of Team Member Effectiveness.* https://engineering.purdue.edu/CATME/index.htm
(47) Ekwaro-Osire, S. and P. Orono, "Design Notebooks as Indicators of Student Participation in Team Activities," *Proceedings of 2007 Frontiers in Education Conference,* Milwaukee, WI, 2007, 1348-53.
(48) Cadwell, K., G. Zenner, N. Chesler, and W. Crone, "Developing Undergraduate Students' Design Skills Using On-Line Video Modules and Active-Learning Exercises," *Proceedings of the 2009 Annual Conference & Exposition,* ASEE (2009).
(49) Interdisciplinary Education Group. *Research and Design Skills.* http://www.mrsec.wisc.edu/Edetc/research/#des
(50) ABET. *2009-2010 Criteria.* http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf

Appendix A: Examples of Rubrics for Grading Design Deliverables

WRITTEN REPORT: GRADING CHECKLIST	**Scores**
Technical Content (60%)	
Topic mastery, including technical correctness	
All requested deliverables included	
Appropriate level of detail and thoroughness of documentation	
Completeness of analysis and interpretation of data	
Organization (15%)	
Clearly identified purpose and approach	
Content is clearly organized and supports the objective	
Transitions between topics	
Presentation (15%)	
Easy to read	
Uniform writing style	
Adequate and consistent presentation of graphics	
Uniform document design and layout	
Correct Grammar and Spelling (10%) (-2 per mistake)	
Total Score	

ORAL REPORT -- GRADING CHECKLIST	
	Score
Technical Content (60%)	
Topic mastery, including technical correctness (20%)	
All requested deliverables included (15%)	
Appropriate level of detail (15%)	
Completeness of analysis and interpretation of data (10%)	
Organization (15%)	
Introduction clearly identifies purpose, approach, and preview of main points	
Content is clearly organized and supports the purpose	
Conclusion provides clear, memorable summary of design	
Introduction and conclusion are tailored appropriately to the audience	
Presenters respond to questions clearly, sufficiently, and succinctly	
Presentation includes logical transitions from one presenter to another	
Presentation (15%)	
Presenters are professional in their dress, language, and style	
Movement, eye contact, & gestures enhance presentation and do not distract from it	
Vocal quality is varied and illustrates interest in topic and design work	
Presenters speak with appropriate pace & volume	
Presenters make reference to other parts of the presentation and connect their part to the whole	
Layout/Visuals (10%)	
Visuals are clear, consistent, readable and understandable	
Visuals accurately follow the oral presentation and provide "visual map" of presentation	
Total Score	

POSTER – GRADING CHECKLIST

Instructions to reviewer: Use these criteria to rate the poster presentation on a scale of 1-5 (1=strongly disagree; 3=neutral; 5=strongly agree).

Appearance	**(5 is strong agreement)**
1. Display attracts viewer's attention.	1 2 3 4 5
2. Words are easy to read from an appropriate distance (3-5 feet).	1 2 3 4 5
3. Poster is well organized and easy to follow.	1 2 3 4 5
4. Graphics and other visuals enhance presentation.	1 2 3 4 5
5. The poster is neat and appealing to look at.	1 2 3 4 5
Content	
6. Content is clear and easy to understand.	1 2 3 4 5
7. Purpose of project is stated clearly.	1 2 3 4 5
8. I understand why someone might be interested in the project results.	1 2 3 4 5
9. There is enough detail about technical results for me to understand the project and recommendations.	1 2 3 4 5
10. The approach taken is appropriate for the problem and technically sound.	1 2 3 4 5
11. Poster is free of unnecessary detail.	1 2 3 4 5
12. Recommendations are stated clearly.	1 2 3 4 5
Presentation	
13. Presenter's response to questions demonstrated knowledge of subject matter and project.	1 2 3 4 5
14. Overall, this was a really good poster presentation.	1 2 3 4 5