How We Teach: Capstone Design

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Dr. Warren D. Seider is a professor of Chemical and Biomolecular Engineering at the University of Pennsylvania. He received a B.S. from the Polytechnic Institute of Brooklyn and M.S. and Ph.D. degrees from the University of Michigan. For many years, he has contributed to the fields of process analysis, simulation, design, and control. In process design, he co-authored FLOWTRAN Simulation—An Introduction and Product, and Process Design Principles: Synthesis, Analysis, and Evaluation. He has co-ordinated the design project course for over 30 years involving projects provided by many practicing engineers in the Philadelphia area. He is recognized for research contributions in phase and chemical equilibria, azeotropic distillation, heat and power integration, Czochralski crystallization, nonlinear control, and safety and risk analysis. He has authored or coauthored over 110 journal articles and authored or edited seven books. Dr. Seider was the co-recipient of the AIChE Warren K. Lewis Award in 2004, and the recipient of the AIChE Computing in Chemical Engineering Award in 1992. In 2011, he received the AIChE F. J. Van Antwerpen Award, and in 2008, he was recognized by the AIChE Centennial Committee as one of "Thirty Authors of Groundbreaking Chemical Engineering Books.” He was elected as a Fellow of AIChE in 2005 and as a Director of AIChE in 1983, and has served as chairman of the CAST Division and the Publication Committee. He helped to organize the CACHE (Computer Aids for Chemical Engineering Education) Corporation in 1969 and served as its chairman. Dr. Seider is a member of the Editorial Advisory Board of Computers and Chemical Engineering.

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Abstract

The authors present the statistical results of the 2012 AIChE Education Division survey on how chemical engineering courses are taught. This year’s survey covers the capstone design sequence as defined by each institution. The survey was conducted of faculty members teaching design courses at their institution during the 2011-2012 academic year. In addition to covering institutions in the United States, the results include a significant number of institutions worldwide who had faculty members participate. Department administrators were solicited via email requesting that the instructors responsible for teaching design at their institution respond to the survey. Later, instructors of record for relevant courses were contacted directly by email and requested to respond. The survey was conducted online using the open-source survey package LimeSurvey. For the first time since the start of this survey series, an incentive consisting of a case study normally sold by the CACHE Corporation was offered to responding faculty members. The report consists primarily of the statistical and demographic characterization of the course and its content, with some additional summary responses related to the course from open-ended questions. Additionally, the survey seeks to bring out the most innovative and effective approaches to teaching the course as cited by instructors. Comparison with a related survey conducted in 1965 is made where appropriate.

Introduction

This survey represents the continuation of a series of surveys of undergraduate curricular topics begun in 1957 by the AIChE Education Projects Committee and more recently resumed by the AIChE Education Division. This paper presents the statistical and demographic results for the fourth in the series of surveys conducted by the Education Division.

Survey Background

The Capstone Design course is the topic of the 2012 survey. The aforementioned AIChE Education Projects committee previously conducted a survey on the same course in 1965. The structure for this report draws heavily on previous reports published on behalf of the Education Division.

The survey was conducted via internet server hosted by the University of Kentucky running LimeSurvey (limesurvey.org). E-mail invitations to participate were initially sent to all 158 department chairs in the United States and later those in Canada requesting participation from the faculty members teaching the relevant course(s). A number of instructors outside of North America were also invited to participate. A separate request was sent to the instructors of record for senior design course during the 2011-2012 academic year based on information posted online.
or made available through department representatives. From that population, 69 usable surveys representing 58 institutions in the United States and 64 institutions worldwide were received.

This 37% U.S. institutional response rate is down from previous surveys, which peaked in 2010 at 42%. This result was surprising, since this is also the first year an incentive of a free case study was offered by CACHE Corporation to all respondents. By comparison, in the 1965 survey the U.S. institutional response rate was 62%.1

Questions were composed in consultation amongst the authors and were intended to provide some continuity with both the current AIChE Education Division surveys and with historical surveys. Respondents were also asked to submit their course syllabus. Information from the 11 syllabi submitted are not included in this report. The complete survey in print form is provided as Appendix A.

**Quantity of Instruction**

Of the sixty-four institutions responding to the question, thirty (46.9%) indicated they offered a single course identified as “Capstone Design”. Twenty-eight (43.8%) offered two courses, four (6.3%) had three courses and one (1.6%) had four courses. Overall, institutions reported 4.1 h/wk total devoted to the course, broken up into an average 2.5 h/wk on lecture, 1.8 h/wk on process simulation or problem solving, and 0.1 h/wk on experimental laboratory.

In the 1965 survey, it was assumed there were two design courses. The time analysis presented in this survey prevents direct comparison of time commitments for the course, but it does appear that time devoted to experimental laboratory work was comparable to that spent on lecture and calculation laboratories in the first design course, but significantly less important in the second course.

**Class Details**

The typical size of a class section as reported by instructors was around 45 students, with some classes as large as 130. The distribution of class sizes is presented as Figure 1.
Figure 1. Section size for a capstone design course as reported by instructors.

Classes are primarily taught by professional instructors, with only 15 programs reporting teaching assistants (TA’s) in a role as lecturer, recitation leader, or oral report evaluator. Thirty-six programs indicated use of industrial partners or adjuncts in one of several roles:

- Guest lectures
- Advisors/mentors
- Consultants
- Evaluators
- Problem sources
- Webinars

While the majority of capstone design courses still retain a regular faculty member in the lead role, a significant number of instructors of other ranks/roles lead this course as shows in Figure 2.
A common concern of industrial employers of chemical engineers is that instructors of chemical engineering often have no industrial experience. Out of the 68 instructors responding to this survey, 15 indicated they had no significant industrial experience. Amongst the 43 respondents with industrial experience there was an average of 11.6 years ($\sigma = 11.2$) of experience reported.

Most programs require group project work, with many also using individual projects, as shown in a summary of deliverables shown in Figure 3. In addition, students in some programs are assessed using other items, including presentations, teamwork, safety training, peer review, status reports, journals, or a mock FE exam.

For team projects, the average team size was 4.3 students, though these results were skewed by several unusually large reported team sizes (>20). When these large teams are removed from the data set, the average team size is 3.5. Within a class, instructors reported an average of 11.8 concurrent (parallel) projects, and 25 instructors indicated that each of their concurrent projects was unique. During the design sequence, a student would participate in an average of 2 total projects.
Figure 3. Deliverables required for the capstone design course in 2011-2012 as reported by instructors.

The projects required by instructors come from a wide-range of sources, as shown in Figure 4. The sources reported in the 1965 report in order of importance were AIChE (excluded from the survey data but assumed based on the question exempting AIChE as a source), the professor’s background, Washington University course materials, and industrial sources.
Figure 4. Sources of projects as reported by respondents.

Figure 5. Process simulation software used in the capstone design course in 2011-2012 as reported by instructors. Use of ProII, Aspen Dynamics, ChemSEP, and Aspen Energy Analyzer were each reported by one instructor.
Mathematical software used in the capstone design course during 2011-12 as reported by instructors. Use of Mathematica, TK Solver, GAMS, and Maple were each reported by one instructor.

Essentially all programs reported some use of process simulation software, with the specific packages applied presented in Figure 5. In addition to steady-state simulation, batch and dynamic simulation were components of instruction. A range of mathematical software was also required in the course as shown in Figure 6. Additionally, programs reported some use of additional software including CAPCost, Visio, Project, and HSC Chemistry.

Instructors reported significant online integration of the course by use of course management systems (Blackboard, Moodle, etc.), use of SACHE materials (especially the certificate program training modules), use of CACHE Corporation materials, and use of other online resources for research.

Textbooks reported as currently in use include (with the most recent edition listed even if a prior edition was in use):

Figure 7 illustrates the distribution of adoption of capstone design texts reported by survey respondents.

The use of textbooks amongst instructors is diverse. Some rely on personal experience and use texts as reference material (if at all). Others seek more case studies, details on methodologies (especially heuristics), and more coverage of ethics, safety, and environment.

Figure 7. Adoption of textbooks. For a particular author, multiple editions may be represented.
Figure 8. Topics taught during the capstone design sequence during 2011-12 as reported by instructors.

Topical coverage during the design sequence as reported in the 2012 survey is presented as Figure 8. The results represent a mix of technical and non-technical subjects, including “professional skills” such as negotiation and conflict resolution. The reputation of the design sequence as a “catch all” course is further supported by the breadth of safety topics covered in this course as shown in Figure 9.
Figure 9. Safety coverage in the capstone design sequence as reported by instructors for 2011-2012. Other topics reported by a single instructor include: human factors, SACHE modules, pressure vessels, codes and standards, corrosion, fires and explosions, NFPA, alarms, containment, process control, and risk assessment.

While alternate specialization tracks exist at many of the institutions represented in the survey, most utilize a common design course while allowing projects to follow specialization tracks. Some require at least one bioprocessing project, and others allow participation in an environmentally focused design competition. One institution allows ChE students to complete an ME design course involving an industry-academic partnership. Another offers a design internship in sustainable engineering, and another has a certificate program in engineering design.

Most programs do not have truly multidisciplinary elements (defined as having students in other engineering disciplines on the design team) in their design course, though many reported efforts to simulate multidisciplinary teams by assigned distinct roles to team members. Some use role playing to simulate multidisciplinary contributions to a project. Other programs do have truly multidisciplinary teams, partnering with ME, CE, and EE students on projects both within the ChE design course and in alternative design courses/projects.

Chemical engineering programs are likely to use this course for ABET outcomes assessment. The fraction of reporting programs using this course for ABET a-k outcomes is shown in Figure
A number of programs post publically accessible rubrics for key elements of their design courses, such as design projects, oral reports, and written reports, such as West Virginia University (http://www.che.cemr.wvu.edu/ugrad/outcomes/rubrics/index.php).

Figure 10. Respondents citing use of the capstone design sequence as part of their program’s ABET outcomes assessment process during 2011-12. Respondents indicated whether the outcome was assessed in their course, and then were asked to identify outcomes which were assessed extensively in the course. Outcomes are: (a) an ability to apply knowledge of mathematics, science, and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, (c) an ability to design a chemical engineering system, component, or process to meet desired needs, (d) an ability to function on an inter-disciplinary team, (e) an ability to identify, formulate, and solve engineering problems, (f) an understanding of professional and ethical responsibility, (g) an ability to communicate effectively, (h) the broad education necessary to understand the impact of engineering solutions in a global societal context, (i) an ability to engage in life-long learning, (j) knowledge of contemporary issues, (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Instructors were asked what their primary goals were when teaching this course and listed a range of goals ranging from higher-level skills to specific engineering performance capability. The goals listed by instructors were:

- Learn critical thinking
- Learn Problem-solving skills
- Develop or demonstrate fundamental competency
• Integrate of concepts from throughout the curriculum
• Full system design with control, economics, and safety

The instructors were also asked to describe their role in the classroom. Some described their role as someone to help students bring out their best performance, describing their role as coach, mentor, team leader, guide, motivator or facilitator. Others saw their role as more technical than motivational, describing the role as an enabler, trouble-shooter, or consultant. A third group used less personal terms, describing their role as teacher, instructor, deliverer of content, or assurer of product quality.

The biggest challenge described by instructors involved class size, and accompanying that challenge was the concern over developing quality project assignments. A number of instructors cited concerns over students, stating that students were “ignorant”, “lazy”, “unable to motivate a semester-long project”, and “unable to handle open-ended problems”. Another common concern was that students seem not to know as much as they should from prior courses, including fundamentals of chemical engineering, how to search the literature, and how to function effectively in teams.

Instructors also noted challenges related to the faculty members charged with teaching the course, stating that they needed experience in plant design, to be engaged with the course, to spend more time grading written work, and not flee the course when asked to teach the course for the first time.

Conclusions

The 2012 AIChE Education Division survey indicates that the capstone design course is a challenging course, with about two-thirds of instructors reporting significant industrial experience providing first-hand knowledge of the practice of engineering design. The breadth of coverage reported justifies the description of the course as a “catch-all”, and it appears to be the primary course in which industrial safety topics are addressed. Even with the common goal of tying together the chemical engineering curriculum, there remains a diverse range of approaches to teaching the course, and a broad range of topics incorporated into it. The range of sources of course materials, especially case studies, appears to have broadened significantly since the previous survey. Additional, use of process simulators is a significant step in the evolution of the capstone design course.

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References

Appendix A. Print version of online survey.