Lessons Learned in the Inaugural Capstone Design Course at Smith College

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Abstract — *The capstone engineering Design Clinic at Smith College was first offered for the inaugural class of engineering majors in the 2003-2004 academic year. Modeled partially after the longstanding program at Harvey Mudd College, the Design Clinic is a year-long course in which teams of four students work on real-world engineering design problems sponsored by industry and government. In conjunction with their ongoing projects, students attend a weekly seminar devoted to team presentations and topics related to engineering design and professional practice. The course is intended to serve as a synthesis of students' previous engineering education as well as a springboard to engineering practice.*

While the inaugural offering of the Design Clinic was a success in many regards, feedback from students and experiences of the instructor identify potential areas of improvement for the future. This paper highlights lessons learned in the first year of the Design Clinic, based on student outcomes, student feedback, focus group results, and instructor observations. In particular, the paper discusses some successful and not-so-successful aspects of the course, including working presentations, team formation and dynamics, liaison selection, project descriptions, seminar topics and guest speakers, evaluation of student performance, and seminar timing. The paper also documents proposed changes to the course in subsequent offerings to improve student learning. While the results in this paper are derived from experiences at Smith, they are applicable to a wide range of institutions; as such, they are presented as a potential resource for instructors seeking either to start a capstone design program or revamp an existing one.

Index Terms — *Capstone engineering courses, design curriculum, design projects, engineering teams*

INTRODUCTION

Established in 2000, the Picker Engineering Program at Smith College is the first engineering program at an all-women's institution in the United States and one of few engineering programs nationally in a liberal arts college. In addition to emphasizing technical competence, the program also applies a learner-centered approach to teaching engineering within a liberal arts setting. Engineering students at Smith receive a broad-based engineering education and graduate with a B.S. in Engineering Science. The first class of 20 engineering students graduated in May 2004; the majority are either continuing their engineering studies in graduate school or pursuing engineering careers in industry.

As emphasized by the ABET accreditation criteria [1], design is an important component of engineering education. At Smith, the engineering curriculum is bookended by design experiences, with additional design elements woven through the intervening courses. Students are initially exposed to engineering design in a first-year "Introduction to Engineering" course, in which they design educational toys for local elementary school classrooms. Students complete their engineering curriculum with a year-long capstone design course, solving engineering design problems for industry and government clients.

Collaborating with my engineering colleagues at Smith and incorporating ideas used in the Clinic program at Harvey Mudd College, I developed this capstone design course, Design Clinic, and served as the course instructor in its initial offering during the 2003-2004 academic year. The course exposes the students to the art and practice of the engineering profession by providing real problems to solve for real clients. In addition, the course serves as an opportunity for students to synthesize and hone their engineering knowledge, applying it in an integrated design experience. The specific learning objectives for the course are as follows:

- To gain experience applying the engineering design process to a real-world problem,
- To apply previous coursework and knowledge to the solution of a real-world engineering design problem,
- To work effectively as a member of team,
- To develop a working relationship with a corporate technical liaison,
- To hone communication skills through oral presentations, written reports, and critiques, and
- To learn about topics related to engineering design and professional practice, so as to gain a better understanding of the impact of engineering in a global and societal context.

DESIGN CLINIC STRUCTURE

Like many capstone course nationwide [2], the Design Clinic consists of two main components: a year-long, team-based design project, and a weekly seminar. Sponsored by industry and government, the projects provide students the opportunity to solve real-world engineering problems for actual clients in collaboration with technical liaisons. This first year, the 20 students in the course worked in four-person teams on five different design projects. The weekly seminar component supplemented the design projects, serving as both a formal and an informal opportunity for learning and sharing ideas in a classroom setting. The seminar sessions included team presentations, engineering design topics, and professional practice lectures, and were intended to aid students during the design process and to introduce them to topics they may encounter in their professional careers.

Design Projects

The five projects were sponsored by both industrial (Ford Motor Company, GE Plastics, Metcalf and Eddy) and governmental (MITRE Corporation, Northampton Department of Public Works) organizations. The projects themselves covered multiple engineering topics, from civil to environmental to mechanical to systems, thus exposing the students to a variety of engineering problems. (Additional details about the projects can be found at www.smith.edu/engin/designclinic/projects) While each student team worked primarily on only one project, the small size and interdisciplinary nature of the Design Clinic course enabled continuous interaction among all five teams during and outside of the seminars, such that each student in the class learned about and contributed to all five projects.

Each project was guided externally by a technical liaison from the sponsoring organization and internally by the course instructor. To facilitate progress, each student team held multiple meetings each week: once with the technical liaison via telephone (and/or in person where possible), once with the course instructor, and at least twice as an individual team. In addition to completing weekly progress reports, teams also produced a project proposal, a mid-year report, a final report, and a final poster. Teams presented their work orally throughout the year, both formally and informally, to various audiences. Team performance was evaluated on the quality of the final product, written work, oral presentations, and overall client satisfaction.

Seminars

The Design Clinic seminar was held weekly on Friday afternoons from 1:00 to 4:00 PM. Periodic seminar sessions were devoted to student team presentations and the remainder focused on engineering design and professional practice topics. Table 1 lists the seminar topics, divided into team presentations and lectures, and the number of seminars for each.

TABLE 1
SEMINAR TOPICS

TEAM PRESENTATIONS (#)	LECTURES (#)
Project Proposal Presentations (1)	Teambuilding (1)
First Working Presentations (2)	Team Dynamics/Effective Meetings (1)
Second Working Presentations (2)	Engineering Design (2)
Third Working Presentations (1)	Project Management (1)
Mid-Year Presentations (1)	Technical Communications (2)
Final Presentations (1)	Sustainability (1)
	Environmental Health and Safety/Regulations (1)
	Engineering Economics (1)
	Engineering Ethics (1)
	Engineering Consulting (1)
	Universal Design/Assistive Technology (1)
	Work/Life Balance Panel (1)
	Starting a Business (1)

Students completed individual assignments in conjunction with the different seminars. For team presentations, each student critiqued another team's presentation, highlighting what the team did well and what it could improve in future presentations. For lectures, students prepared written feedback summarizing their rating of the seminar and suggested changes. In addition, for selected seminars, students wrote essays or completed homework problems. Individual student

performance was evaluated as a combination of individual assignments, in-class participation, and contribution to the team project.

LESSONS LEARNED

Overall, the inaugural offering of the Design Clinic was a success, in part because many aspects of the course mirror those of other established capstone courses across the country. Information about some of these valuable components has been published elsewhere [3]-[8]. Success notwithstanding, the course would benefit from some specific modifications, as identified by student feedback (from course evaluations and focus group discussions) and instructor experiences. This paper highlights the lessons learned, documenting the selected approaches used, the resulting feedback, and proposed changes. In particular, the sections below detail one new positive development and several areas for improvement. Although the results from the inaugural year are largely qualitative, the lessons learned are presented to aid instructors in the development/improvement of new or existing capstone courses.

Working Presentations

One interesting successful technique implemented in the Design Clinic was a series of themed "working" presentations. As listed in Table 1, student teams were required to make oral presentations multiple times throughout the course. These presentations ranged from formal presentations in front of a wide audience to informal working presentations in class. The intent of the working presentations was to encourage each team to focus on selected aspects of their design projects, communicate this informally to their class, and engage their fellow classmates. Each working presentation had a designated theme and a set of guidelines for the presentation style, as shown in Table 2.

TABLE 2
WORKING PRESENTATION DETAILS

WP #	Theme/Assignment	Date	Time	Guidelines
1	*Work-Through*: lead guided discussion to gather input and feedback from classmates	Oct./ Nov.	50 minutes	No PowerPoint slides; instead may use written notes, white board, handouts, overhead transparencies
2	*Technical*: present technical/logistical aspects of design project in detail	Feb.	50 minutes	Equations/diagrams/figures encouraged; PowerPoint slides can be used sparingly
3	*Visual*: present design projects through graphics, rather than text	Apr	30 minutes	PowerPoint slides with heavy graphics; no bullet lists of text

The working presentations imposed constraints on the teams, requiring them to think about their design projects in different ways. The themes forced the teams to focus on specific aspects of their project (rather than presenting everything each time). The guidelines mandated different presentation styles, thus providing opportunities to try various presentation techniques. In addition, the three presentations (in particular the third one) encouraged the teams to develop materials they could use in later deliverables, such as their final presentation and poster. Students were also assigned to evaluate another team's working presentation, and submit a thoughtful, constructive critique of the other team. I compiled the results from the critiques (a time-consuming, but enlightening, process) and distributed an anonymous compilation to each team for use in improving future work.

Student response to the working presentations was positive. Students were asked to rate the effectiveness of the working presentations as a learning tool; on a scale of 1 to 5 (1=not effective, 5=highly effective), 80% of the students rated it a 4 or 5. Several students commented on the final evaluation that they enjoyed being an active part of each project and working as a class. Students in the focus group noted that they enjoyed watching each other's presentations as well as having variety in the different working presentations.

The three working presentations were a highlight of the Design Clinic for several reasons: (1) they served as internal milestones in the design process, (2) they strengthened the oral communication skills of all the students, and (3) they enabled interactions and discussions among teams, such that each student participated to some degree in all five design projects. Future offerings of the course will include the three working presentations described above in addition to a fourth one focused on the constraints governing each design project, a particularly important component of the design process and one emphasized by ABET [1].

Team Formation and Dynamics

Teams were formed entirely through student project preference. During the first class, I distributed short descriptions of each of the five projects. The students then completed a "project preference form" in which they selected their first and second choices, explained reasons for selection, and indicated whether they were interested in being project manager. I compiled the results on a spreadsheet and created the teams – a task that could have been quite complicated and required many decisions on my part. Amazingly, however, the student preferences this first year were divided so evenly that 19 students received their first choice and the 20th received her second choice.

Although project preference was evenly distributed, personality and interpersonal skills were not. A Meyers-Briggs assessment conducted after the team formation revealed that all of the teams displayed disproportionalities in at least some areas of personality, some teams more than others. In part to address these discrepancies, I devoted the second seminar to team dynamics; members of each team were encouraged to assess their individual and collective strengths and weaknesses and determine strategies for successful collaboration. Success varied among the teams in addressing interpersonal dynamics. Some of the teams quickly recognized potential stumbling blocks in their team dynamics and worked diligently to avoid them. Others, however, encountered more trouble; one team was plagued so extensively by unbalanced team dynamics and interpersonal clashes that their design progress was hampered and their final result was less than satisfactory. I spent many meetings with this team mediating personalities rather than advising the design process.

While student project preference is clearly important, for students will work best on projects they enjoy, the experiences from this past year underscore the additional importance of functional teams and the need to balance interpersonal skills and personality. Assigning teams based on preference and then identifying (and, ideally, working through) potential disfunctionality on teams seems somewhat backwards. In fact, other capstone instructors have found that the most functional and successful teams are formed based exclusively on personality [9]. Given these insights, the strategy I will use next time is to incorporate both personality and project preference from the beginning, with personality as the driving variable. I plan to assess personality following Doug Wilde's creative team methodology, which incorporates elements of the Meyers-Briggs Type Indicator and Jungian philosophy [10]. Teams formed following this latter approach may still not be ideally balanced, but they have a better chance of functionality, thus enabling them to spend more time on engineering design and less on conflict mediation.

Technical Liaisons

The technical liaisons for the projects were chosen by the sponsoring organization. During project negotiations, I informed the main contacts at the sponsoring organizations of the importance of the liaison role and estimated time commitment (2-4 hours per week), and gave them the flexibility to select an appropriate person. Prior to the start of the course, I talked briefly with each of the liaisons to discuss course/project logistics, but did not (in part due to time constraints) gauge the liaison's interest, discuss advising in depth, or seek to request a different liaison. During the course, I checked in periodically with the liaisons, primarily to discuss deadlines and deliverables. In my limited interactions with them, I found the liaisons for the most part to be responsive to my questions and suggestions, attentive to deadlines, and interested in the progress of their respective teams.

Students, on the other hand, had mixed experiences with their liaisons. Table 3 shows results from two liaison-specific questions on the final course evaluation.

TABLE 3
STUDENT RESPONSES TO LIAISON-SPECIFIC STATEMENTS ON FINAL EVALUATION

Final Evaluation Statement	Number of Students Responding				
	strongly disagree	disagree	neutral	agree	strongly agree
1: My liaison was clear about his/her expectations of my team during this project.	5	4	2	4	5
2: Overall, my liaison was a valuable component of the design project experience.	4	1	5	2	8

All eight students who responded "strongly agree" to the second statement and eight of the nine who responded "agree" or "strongly agree" to the first statement were from two teams, thus illustrating that two teams (but only two teams) had positive experiences with their liaisons. Difficulties for the other three teams arose when students perceived that the

liaison was (1) not invested in the project (likely as a result of having been "assigned" to it), (2) too busy with other work for regular communication, or (3) not tremendously knowledgeable about the specific project.

Overall, students' experiences were affected to a great extent by interactions with their liaisons. As one student noted in the focus group, "Either you have a great project, and you can directly relate that to having a really good technical liaison, or you feel very frustrated about your project, which is also directly related." The two teams that had excellent relationships with their liaisons were motivated and excited by their projects. In contrast, the other three teams reported frustration with their lack of relationship and effective collaboration, as well as jealousy of the other teams.

Some of the teams' disappointing liaison experiences could have been addressed with more involvement, especially early in the process, by me as the course instructor. In future offerings of the course, I will look for liaisons who demonstrate a true excitement about working with the student teams and an investment in the project. Moreover, I plan to talk at greater length with the liaisons before the course starts about the pivotal nature of their role and encourage regular communication (with me and the teams) throughout the year. As students suggested on the final evaluation, future liaison selection should identify people who "are very excited about working with students," "want to be involved," "have the time for the project," and "have in-depth knowledge of the field [in which] the project is going to be applied."

Project Descriptions

Some of the team dynamics and liaison issues may be attributable, in part, to differing expectations about the projects themselves. Prior to the start of the semester and following phone and email conversations with contacts at the sponsoring organizations, I wrote short project descriptions for each of the five projects. These descriptions included a one-sentence summary of the project and a one- or two-paragraph overview of the project scope. I sent each description to the appropriate technical liaison for comments, edited them as necessary, and then distributed them to the students during class. The advantage to this approach was that all of the descriptions were consistent in tone, format, and extent of information provided.

Student feedback was mixed. The approach led to discrepancies between students' expectations and their actual experiences as shown in Table 4.

TABLE 4
STUDENT RESPONSES TO PROJECT-SPECIFIC STATEMENTS ON FINAL EVALUATION

Final Evaluation Statement	Number of Students Responding				
	strongly disagree	disagree	neutral	agree	strongly agree
1: The overall description/scope of my project was clear from the beginning.	8	1	4	4	3
2: The type of work I completed on my project was what I expected from the beginning.	5	3	5	3	4
3: Now that I know more about all the projects, I would still choose my project (and not another) if I had to do it again.	5	1	4	1	8

For the first two statements, all of the "strongly disagree" and "disagree" responses come from students on three of the five project teams, whereas, with one exception, all the "agree" and "strongly agree" responses come from students on the other two project teams. Clearly, then, only some of the project descriptions provided sufficient information to guide the students and align expectations with experience. In light of the results of the first two statements, however, it is interesting to note the students' opinion about their project selection, as documented in the third statement. The eight students who responded "strongly agree" were members of the two teams associated with the positive results in the first two statements, and also the same ones who reported very positive liaison experiences (see Table 3). Accurate expectations and positive liaison experiences are therefore two indicators of project satisfaction.

The three main reasons the project descriptions did not yield accurate expectations were that they (1) were not written directly by the sponsoring organizations and thus did not necessarily exactly reflect their goals, (2) did not explicitly list the intended deliverables, and (3) perhaps most importantly, did not address the intended implementation of or future plans for the projects once the students completed them. In an effort to address these shortcomings, I have now instituted a "Project Summary Form" to be completed by all sponsoring organizations. This form, which includes sections on project scope (including description of the design elements, background, motivation, list of deliverables, and implementation plans) will require the sponsors to describe clearly, in their own words, their goals for the student teams and plans beyond. While

student expectations about their projects can be altered over time, their initial expectations certainly contribute to their experiences and, ultimately, their end product.

Seminar Topics/Guest Speakers

The seminars were divided between team presentations and lectures or panels on topics related to engineering design and professional practice. Several of the lectures were taught by the course instructor, but the majority were presented by guest lecturers who were specialists in a particular area/topic. In all, 17 guest speakers contributed to the class during the year, either as individual lecturers or as part of a panel. Lecturers were usually allotted the full seminar time (or at least half of it) to present their topics. In select cases I developed individual and/or team assignments about a given topic, but for the most part, the lectures were stand-alone units without related homework.

The intent of the seminars was to teach the students about a wide range of topics presented by experts that would be useful for their design projects and potential future engineering careers. Although all of the guest lecturers were knowledgeable about their topics, unfortunately they did not always deliver the information in an engaging, interactive format. Many of the resulting lectures were not particularly learner-centered, and students often tuned out relevant material. In anticipation of this potential shortcoming, during the second semester I identified the learning objectives for the day at the beginning of each class, an approach that seemed to focus the students' attention somewhat, though did not necessarily impact a lecturer's style! Moreover, the lectures were not well connected with the design projects, in part because the various lecturers were simply not intimately acquainted with the different project details and because of the lack of individual or team assignments before or after each lecture that could have strengthened the connections and reinforced the students' learning. Finally, the sheer number of uncoordinated guest speakers in the Design Clinic created inconsistencies that compromised the coherence of the course overall. As seen in Table 5, student response to the seminars reflected perceived inapplicability (especially with regard to design topics), though is interesting to note that most of the students found the seminars valuable overall.

TABLE 5
STUDENT RESPONSES TO SEMINAR-SPECIFIC STATEMENTS ON FINAL EVALUATION

Final Evaluation Statement	Number of Students Responding				
	strongly disagree	disagree	neutral	agree	strongly agree
1: From the seminars, I gained knowledge I could apply directly to my design project.	4	3	10	3	0
2: From the seminars, I gained knowledge to help me prepare for a career in engineering.	0	2	5	10	3
3: Overall, the seminars were a valuable component of the course.	0	0	4	10	6

Plans for the future include significantly reducing the number of guest speakers such that guests supplement, rather than constitute, the course. I will invite guest speakers for areas where their expertise is particularly valuable or necessary. Through the addition of individual or team assignments and activities, appropriate topics (such as project management and engineering economics) will be linked directly with the design projects. More emphasis will be placed on informal presentations by individuals and teams on design-related topics, so as to further engage the students and make them responsible for their learning. Similarly, student suggestions for topics and/or guest speakers in the spring will be solicited in the fall, providing students an opportunity to contribute to their learning. Finally, as course instructor, I will frequently review and discuss the schedule for upcoming lectures, as well as the rationale for the organization, so that expectations match experiences and the components of the course come together as a coherent whole, rather than assorted pieces.

Performance Evaluation

Student performance in Design Clinic was assessed as a combination of individual and team performance. Table 6 lists the graded components within each category and their weights as a percentage of the overall course grade. "Team Contribution" grades were based on peer evaluations completed by all members of each team, in addition to instructor input. Likewise, "Overall Project Success" grades were based on the evaluation of each team's technical liaison, in addition to instructor input. All other grades were based on instructor evaluation. The team assignments were prefaced with guidelines about what to include, but none explicitly specified grading rubrics.

TABLE 6
GRADING SCHEME

Overall Course Grade (100%)	
Individual Grade (35%)	**Team Grade (65%)**
Individual Assignments (15%)	Progress Reports (10%)
Class Participation (10%)	Written Proposal (5%)
Team Contribution (10%)	Mid-Year Report (10%)
	Mid-Year Presentation (5%)
	Final Report (20%)
	Final Presentation (5%)
	Overall Project Success (10%)

Grading a capstone course such as Design Clinic is a challenge in part because so many different evaluation factors contribute to overall performance. How best to identify and appropriately evaluate these factors (such as technical accuracy, completeness, clarity, organization, communication, teamwork, client relations, grammar, spelling, etc.) proved a learning experience for me. For the "Team Contribution" evaluation, students filled out a form that clearly listed the factors for assessment (attitude, cooperation, communication, initiative, etc.), a manageable task required once each semester and done successfully by the whole class. Completing such a process to evaluate weekly progress reports for five different teams, on the other hand, would have been a prohibitively time-consuming task, so the simpler and more efficient approach I used was to assign a single "one-point" grade that roughly reflected the combination of factors. The absence of a clear evaluation rubric (particularly on assignments that reflect many areas of performance), however, can lead to three main problems. First, students do not understand how their grades are calculated and therefore have difficulty prioritizing how to improve. Second, single "one-point" grades can overlook important evaluation factors, especially for collections of assignments or deliverables built upon previous ones. For example, one team submitted organized progress reports clearly documenting what they had completed and what they were planning each week; the good grades they received on the individual progress reports misrepresented their overall project success, since, taken collectively, the progress reports followed a work timeline far slower than what was needed to complete the project successfully. Third, maintaining consistent grading across different students and assignments can be challenging. In an effort to balance effective feedback and reasonable time requirements, I plan in future offerings to employ evaluation rubrics for the major assignments but limit grading of smaller (and more regular) deliverables such as progress reports to comments only. I also plan to increase the weight of "overall project success", minimizing the risk that grades on interim deliverables overshadow the ultimate results of the project.

Seminar Timing

As noted previously, the year-long design projects were accompanied by a required weekly seminar. The seminar itself was a tremendous benefit to the Design Clinic overall, since the regular meeting time promoted interactions among and within teams, enabled opportunities for team presentations, and provided times for lectures and discussions on topics related to design and professional practice. The timing of the seminar – Friday afternoons from 1:00 to 4:00 PM – was both good and bad. One advantage to the Friday time slot was that Design Clinic conflicted with few, if any, other courses. Moreover, Friday afternoons proved a convenient time for guest speakers, especially those traveling from any distance. Also, the three-hour time slot was useful for long seminar sessions, such as panel discussions or hands-on activities. The drawbacks of the Friday afternoon class outweighed the benefits, however. From a student perspective, three hours is a long time to focus on anything, especially on a Friday afternoon; learning is better spread out in shorter, more frequent, periods. As I quickly realized, even the most engaging guest speaker cannot easily hold the attention of a class of seniors at 3:30 PM on a Friday afternoon in a poorly ventilated classroom! (Including a required 15-minute break – with food – in the middle of each class did help to reenergize the students to some extent.) Another disadvantage of the once-weekly class was that if a student missed one class, she missed an entire week of material; Fridays proved to be particularly plagued by absences in the spring, since many of the students traveled on job interviews or graduate school visits. Additionally, rescheduling guest speakers in times of conflict or weather (we had two classes cancelled due to snow) proved difficult with such limited class frequency.

The next offering of the course will add a 1.5-hour slot on Monday afternoons to the existing 3-hour Friday afternoon slot. Of the 4.5 hours reserved for the course, three hours will be used for the seminars and the remaining 1.5 hours will be devoted to team meeting time in class during which I will be available for consultation. Most weeks the seminar will meet both Mondays and Fridays (for 1.5 hours each), except when the continuous 3-hour Friday slot is needed. This arrangement will allow more frequent class discussions and learning, provide scheduling flexibility, and provide regular team meeting time during class – something the students this year would have liked and had expected.

CONCLUSIONS

The inaugural engineering Design Clinic was offered at Smith College in 2003-2004, providing engineering seniors with a year-long, capstone design experience. The course comprised two main components: an applied, team-based, design project sponsored by industry or government and a weekly seminar on topics related to engineering design and professional practice. The course was a success in many regards: nine of ten students in the focus group rated the course excellent, very good, or good overall; one students noted, "I'm moving into the field I completed my project in. And that was not where I intended to go."; and all of the initial project sponsors are interested in continued collaborations in future years.

Student feedback and instructor experiences also suggest improvements that could be implemented in future offerings. In particular, the main lessons learned include the need to:

- Encourage periodic "working presentations" in which teams share their progress and harness their classmates' input,
- Incorporate personality and student preference when forming teams,
- Select technical liaisons who are invested in the project and excited to work with students,
- Provide detailed project descriptions that list project deliverables and plans for implementation,
- Include in-class and take-home activities that connect the seminar topics with the design projects,
- Utilize guest speakers to supplement, rather than constitute, the course,
- Implement a grading rubric for major assignments (such as a final report) that evaluate many factors,
- Avoid scheduling the weekly seminar exclusively on Friday afternoons, and
- Above all, communicate expectations clearly and frequently.

Coordinators and instructors of similar capstone courses should consider the lessons learned in this inaugural course, so as to provide a more successful and informed design opportunity for their students.

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