120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #6997

Implementation of a "Rapid Design Challenge" in a Cross-Disciplinary Senior Capstone Course and Evaluation of Device Performance

Mrs. Abby M Kelly, University of Nebraska, Lincoln
Dr. David Jones, University of Nebraska, Lincoln
Dr. Roger Michael Hoy, University of Nebraska
Evan Curtis, University of Nebraska, Lincoln
Dr. Angela Kaye Pannier, University of Nebraska, Lincoln
Dr. Richard R. Stowell P.E., University of Nebraska, Lincoln

Implementation of a "Rapid Design Challenge" in a Cross-Disciplinary Senior Capstone Course and Evaluation of Device Performance

Abby M. Kelly, Austin Lammers, David D. Jones, Richard Stowell, Roger Hoy, Evan Curtis, Angela K. Pannier
Department of Biological Systems Engineering, University of Nebraska-Lincoln

Abstract

The senior capstone experience within the Department of Biological Systems Engineering at the University of Nebraska-Lincoln is a two-semester, two-course sequence intended to give senior students realistic design experience, working with real projects, real clients, faculty consultants, and teammates to produce a deliverable that meets the client's needs. Students within this course sequence come from two different degree programs (agricultural engineering and biological systems engineering) and within each degree program from a variety of "emphasis areas", e.g. biomedical engineering, environmental engineering, machine design. While the goal of this course is for students to experience a "real" design project, we felt that we needed to improve this senior design sequence with an exercise that forced all students through a shared and "complete" design process to help address some of the challenges associated with a cross-disciplinary capstone course. Therefore, beginning in 2010, a two-week, rapid design challenge was implemented at the beginning of the senior capstone design experience, based on a similar challenge developed at Bucknell University[1]. This abbreviated design experience challenges the students to rapidly learn and implement the basic steps of design to produce a functional prototype, which is displayed and tested during a design challenge competition. The challenge presented to students is to design and build a device for a third-world clinic to infuse a cholera treatment solution, at a specific flow rate and time for injection, with specific technical constraints. During this two-week challenge, multiple assignments help move the students through each phase of the design process. Teams are given a budget and time to build, test, and iterate their design before the final competition between teams. The team with a device that most closely achieves the dictated criteria wins the competition. To evaluate the performance of each team, a National Instruments (NI) data acquisition system was developed, which combines NI LabVIEW software and two Micro Motion Coriolis flow meters. The system evaluates multiple parameters of the design, and combines the data with faculty judge evaluations to calculate an overall score. Team scores are displayed on a digital scoreboard throughout the competition. The Rapid Design Challenge (RDC) is then used as an example to introduce future topics in the course. Finally, the RDC has been critically evaluated over four semesters of implementation as part of the continuous improvement and assessment process. This exercise has revitalized the course and ensured that all students share a common and successful design experience.

Introduction

The Importance & Challenge of Capstone Design Courses

Senior capstone design is typically the first real-world experience undergraduate engineering students receive within a classroom setting. While many undergraduate programs contain elements of design and small-scale design projects within a four-year curriculum, capstone design is often the only large-scale project with real clients, budgeting, and potential real-world implementation. Working with clients and in teams on problem identification, design development, and solution implementation are the best preparation for a career in any engineering field[2].

With the importance of senior capstone courses so high, the challenges associated with them are equally high, both in number and scope. Challenges frequently associated with senior capstone design courses, as described by others[1] and experienced in our course are as follows:

1. <u>An atypical course format:</u>
   Typical undergraduate courses follow the classic structure of lectures, homework, labs, and exams. Capstone courses are centered on nontechnical lectures, project benchmarks, student presentations, and design reviews. The nontraditional course format is jarring to many students.

2. <u>Unfulfilling first semester</u> (for two semester capstone sequences):
   When capstone design is a two-semester long course, there is typically no tangible deliverable upon completion of the first semester. The first semester is focused primarily on research, project management, and brainstorming. As a result, many students report feeling disappointed at the end of the first semester.

3. <u>Project variety and lack of class unity</u>:
   In most undergraduate courses, even with group projects, all students work on the same project. Teams can work together and discuss problems. However, in senior capstone design, each team works on different projects with different client needs, criteria, and constraints. As a result there is frequently a lack of class unity.

4. <u>The trap of iterative design</u>:
   While many of our core courses contain design projects, capstone design is a student's first long-term design project. For most students, capstone design is the first time they spend a considerable amount of time researching, developing multiple designs, testing a design and then reworking it. Consequently, many students stall in one or more phases of the design process and are unable to progress forward.

5. <u>Introduction to the complete design process</u>:
   While not the case in our program, for many students, senior capstone design is their first introduction to the complete design process. Lack of adequate design experience can be a major obstacle to producing effective final designs, but more importantly a major

obstacle in getting the maximum benefit from the course and the learning process that comes with completing a real engineering project.

Across the country, these challenges become compounded as enrollment numbers continue to rise in biological engineering departments. According to the 2011 annual ABET review, bioengineering and biomedical engineering programs saw a 98% increase in the number of ABET accredited programs added in the US over the last 6 years, the highest for all engineering disciplines. In fourth for largest increase was environmental engineering at a 20% increase[3]. These disciplines are all represented within the department of Biological Systems Engineering (BSE) at the University of Nebraska-Lincoln (UNL).

The Agricultural & Biological Systems Engineering Capstone Course at UNL

The BSE department at UNL was one of the first programs of its kind in the country when it was established in UNL. Our program is ABET accredited and has been ranked in the top 10 programs of its kind by US News and World Report[4]. The department houses two engineering degree programs: agricultural engineering and biological systems engineering. Within each of these programs students specialize in one of three emphasis areas.

Agricultural Engineering emphasis areas:
- Machine Design
- Soil & Water Resource Engineering
- Test Engineering

Biological Systems Engineering emphasis areas:
- Biomedical Engineering
- Environmental Engineering
- Food & Bioproducts Engineering

Our senior capstone course sequence, AGEN/BSEN 470/480, is a two-semester long course (4 credit hours total), for seniors only, designed to give students a real-life design experience. The year-long course is comprised of lectures, guest speakers, and exercises designed to enrich and enhance the capstone project, which is presented formally through design reviews, and student presentations. Students work in teams with real clients on real projects. Projects come from clients such as: local industry professionals, design engineers, engineering consultants, surgeons from the University of Nebraska Medical Center, and professors from within UNL. In addition to their client and the course instructors, teams are also assigned a faculty consultant who specializes in the area most similar to their project. Students must draw upon all of their previous knowledge as well as consult with their client, faculty consultant, and other outside sources in order to define their problem, gather information, synthesize usable criteria and constraints to help guide their final design, and finally, they must apply appropriate technical knowledge and practices to develop the best engineering solution to meet their client’s needs. Throughout the two semesters, teams must work through the design process, produce test data, and reiterate the design process to make improvements on their final design. Final designs, or deliverables, can include models, design schematics, prototypes, and in some cases functional products. The course culminates in a written technical report and an oral presentation given to the department, their fellow students, and clients. Some previous capstone projects include: a stream restoration project, development of an integrated energy and production system for a swine finishing operation, design of a 3D imaging system for orthotic production, design of a standing column well for geothermal energy, development of a post-hole digger evaluation device, design of a radiation shield for the hepatic artery, design and development of a quarter-scale tractor, design of an automated weight filling mechanism for a pilot-scale ice cream manufacturer, design and instatilliation of a laboratory-scale water pump facility, and design of a minimally invasive mitral valve surgical heart retractor.

The cross-disciplinary nature of the two degrees and six emphasis areas in the BSE department creates additional challenges in the implementation of a capstone design course. Students, while grounded in agricultural or biological systems engineering, have diverse backgrounds and interests in automotive, biomedical, bioprocess, chemical, civil, computer, electrical, environmental, and mechanical engineering. Due to the diversity of student interests, many teams are cross- disciplinary. While challenging, especially to instructors that must manage multi-disciplinary teams and a tremendous variety of projects and clients, cross-disciplinary teams have been shown to be highly advantageous to students, both in courses and in their future careers. Multi-disciplinary teamwork has been shown to produce better engineering design solutions, foster more effective communication skills, and even greater odds of employment after graduation[5].

Unique Challenges for UNL BSE Capstone Course

As stated above, our cross-disciplinary senior capstone course sequence, with students from two engineering majors and projects spanning six emphasis areas, presents many unique challenges. In addition to the challenges outlined previously, it was critical to the success of our students and our department to also address the following issues:

1. Slow-paced, nontechnical lectures:
   Engineering students in particular are accustomed to fast-paced courses full of technical skills. The format of typical capstone design lectures seems slow and the topics of lectures are outside their typical scope.

2. Project and time management:
   Prior to the capstone course, many students have not developed adequate time management skills to handle a year-long project. In typical classes, students are kept on track through the regular submission of coursework and scheduled exams. Except for the initial research phase of design, regularly scheduled coursework is not conducive to the iterative design process that occurs in real life and in the capstone course. For this reason, many students have a hard time staying on track, and find themselves scrambling during the last half of the second semester of the capstone course sequence

3. Team dynamics in cross-disciplinary teams:
   To best mimic "real life" engineering design projects, capstone courses often involve design teams. Yet, the students in the Agricultural and Biological Systems Engineering programs span a wide range of specialties resulting in cross-disciplinary teams.

Development of a working team dynamic, even within mono-disciplinary teams is often very difficult and as a result, many teams never function effectively.

4. Integration of faculty consultants:
   To help overcome the burden on faculty members as a result of cross-disciplinary teams and the wide range of student specialties, faculty consultants are assigned to each team. However, many students do not regularly meet with faculty, nor have students ever worked side-by-side with a faculty member on a project previously in their undergraduate career.

Finally, upon completion of student projects at the end of each academic year, clients of our student teams are asked to complete surveys regarding the team's performance. These surveys are used for continuous improvement and as part of our departmental assessment and accreditation process. Client surveys from 1999 to 2005 reiterate results seen in many national reports, which highlight a need for improvement in verbal and written communication, business and soft skills, and teamwork, specifically with diverse and interdisciplinary groups[2]. An emphasis on these skills as well as a more rapid method of developing them is needed within the senior capstone design sequence.

Like other universities, we have found that our traditional approach to the teaching of capstone design is not addressing all of the challenges discussed above. As a means to begin to address these issues, our department implemented a two-week rapid design challenge (RDC), similar to the challenge developed by Bucknell University[1]. The RDC was adapted to better suit our needs and initially implemented in the spring of 2010. The challenge has been conducted four times and critically evaluated after each semester. Here, we present our rapid design challenge, and the unique characteristics of its implementation, evaluation, and continuous improvement.

Rapid Design Challenge (RDC) Concept

The Bucknell University Model

Tranquillo and Cavanagh from Bucknell University implemented a RDC within their biomedical engineering capstone design course in 2007. This challenge was discussed at length in their ASEE proceedings paper[1]. Briefly, they implemented a three-week challenge designed to take students through each of the major phases of the iterative design process.

Students were divided into teams and asked to design a Cholera treatment infusion device that would deliver 60 cc of fluid, over 10 minutes, at a constant rate of 6 cc/min., with a budget of $100. The device could not use an external power source, it needed to be portable, and once started had to operate without any manual intervention. Five assignments were due to highlight the major milestones of the design process and coordinating lectures were given.

Student devices were evaluated on three criteria: their ability to delivery 60 cc of fluid in 10 min. and at a rate close to 6 cc/min., and general creativity and ingenuity as judged by faculty. Evaluation of student designs took place at a competition where students presented their design approach and discussed the features of their final designs. Winning designs were awarded prizes[1].

Initial Implementation of a RDC at UNL

We first implemented the RDC in the spring of 2010. The premise of the design challenge was very similar to that at Bucknell Unviersity[1]. However, we changed several of the details to better fit with the challenges and features of our capstone course sequence.

We maintained the general premise of the challenge: to design a Cholera treatment infusion device to deliver 60 cc of fluid, over 10 minutes, at a constant flow rate, with a budget of $100. The device also had to be portable, without the use of electrical power, and must operate without manual intervention. Teams were selected randomly and were encouraged to keep their designs confidential from other teams. However, we changed the duration of the challenge, the nature and quantity of the assignments, and the way in which student designs were evaluated, as compared to the exercise at Bucknell University.

RDC duration

To address the challenges of slow-paced, non-technical lectures, as well as the issue of time and project management, we gave students just two weeks to complete the RDC (See Figure 1 for an example timeline). Getting through all the major phases of design in only two weeks makes the experience more challenging for students, gives a sense of urgency to what might be considered slow-paced lectures, helps students to remain on schedule, and heightens the need for efficient project planning and management of time and personnel.

Design Challenge Schedule

Date	Activity	Assignment Due
8/31/12	Introduction to Challenge and Problem	
9/4/12	Work on User Needs/Initial Brainstorming	#1: Memo with Problem Statement
9/5/12	Work on Functions/Specifications	#2: Users and Needs Worksheet
		#3: Memo with List of Preliminary Ideas
9/6/12	Work on Solution Generation, Analysis , Planning	#4: Specifications Worksheet
9/7/12	Teams meet with Consultants	#5: Alternative and Final Solution Worksheet
9/10/12	Prototype and Testing	
9/11/12	Prototype and Testing	
9/12/12	Prototype and Testing	#6: Memo with Testing Results with List of Planned Improvements
9/13/12	Redesign and Final Fabrication	
9/14/12	Class: RAPID DESIGN CHALLENGE COMPETITION	Presentation and Prototype
9/21/12	Wrap up and discussion	#7: Evaluation of Rapid Design Process

Figure 1: Two-week rapid design challenge schedule for Fall 2012 semester

Assignments

Students complete six assignments prior to the RDC competition to help move them through the design process. The assignments guide them to develop a problem statement, user needs, technical specifications, alternative solutions, testing procedures and data, and a final solution. Additionally, as part of their final solution selection assignment, students were required to get design approval from their faculty consultant. Finally, students complete an end of project survey to encourage both individual and group reflection on the overall design process (Appendix I). Unlike at Bucknell University however, students were asked additional questions in the survey about the RDC itself to help faculty in the continuous improvement process and to help determine the effectiveness of the RDC at addressing the capstone design challenges outlined above. The survey consisted of nine questions:

1. How did your team perform? Did you stay on schedule? Why or why not?
2. What were the main challenges in completing the project?
3. What do you feel were the strengths of your team's effort?
4. What do you feel were the weaknesses of your team's effort?
5. If you were to do it again, what would you do differently with regards to your teams' process?
6. Reflect on your own individual role in the project.
7. What were the strengths of the design challenge exercise as it was presented and defined?
8. How could the design challenge be improved in the future?
9. What skills from the design challenge do you think will aid you in your upcoming senior design project?

Each semester, these surveys are qualitatively and semi-quantitatively assessed. As a result, additional changes were made to the RDC with each iteration of the course. The surveys were also analyzed as part of the assessment for the AGEN/BSEN 470/480 capstone sequence for the 2011 ABET review. These results will be discussed in greater detail later.

Design Testing and Evaluation

At Bucknell University, students were able to test their designs prior to the competition by simply timing their device and measuring total volume delivered. During the competition, student designs were evaluated based on total volume of fluid delivered, total time, an average flow rate, creativity and ingenuity[1]. However, we felt that the continuous flow criteria was a critical component to measure. Therefore we created a system to automatically and more accurately evaluate student designs for their ability to meet criteria. To evaluate each student design, we created a semi-automated system using LabVIEW and a Micro Motion Coriolis flow meter. The program was created to measure instantaneous flow rate, flow rate standard deviation, average flow rate, total volume of fluid delivered, and delivery time. The program calculates a final score for team performance.

Department faculty are invited to the competition to judge as well as observe and encourage our students. Judges are given evaluation forms (see figure 2) that reflect the given criteria and constraints of the project. Faculty judges base their scores on team presentations as well as design performance. Teams are given 5-10 minutes to describe their final design and their design process. After all student teams have competed, faculty judge scores are combined with the team performance score calculated by the LabVIEW program. Prizes are awarded to the three highest scoring teams.

AGEN/BSEN 470 Rapid Design Competition Score Sheet	
Team Name/Number:	
Apparatus is portable.	of 25
Materials are appropriate for 3rd world setting.	of 25
Satisfies $100 cost limit.	of 25
Apparatus requires no intervention.	of 25
Quality of Design	of 25
Quality of Presentation	of 25
Total/Comments:	of 150
Judge:	

Figure 2: Faculty judge evaluation form

Evaluation and Improvement of the RDC

In addition to encouraging individual and group reflection on the design process, one of the primary objectives of the student survey is for faculty to improve upon the RDC for future semesters as part of the continuous improvement and assessment process.

Continuous Improvement

At the end of each of the four semesters for which the RDC has been used, student surveys were qualitatively assessed, and changes were made to the design challenge with each iteration of the course.

The surveys from the spring of 2010 provided tremendous feedback from the first implementation of the RDC and the majority of the changes that have been made to the RDC were made as a result of the first semester evaluations. Specific issues that elicited change were:

- An overwhelming majority (70%) of students from the first semester would have liked to compete with their actual capstone design groups. In a cross-disciplinary program, development of effective team dynamics is a big challenge in creating the best engineering designs possible. Students recognized this issue. To help expedite this process and force students to quickly identify and address their own and their teammates strengths and weaknesses, we put students into their final design teams for the second and all future iterations of RDC.

  However, to accommodate this, advanced preparation on the part of faculty is required. Clients must be identified earlier and students must be surveyed about which projects they most wanted to work on prior to the start of the semester, so teams can be assigned on day one.

- Additionally, 40% of students from the first semester stated a desire to have access to the actual equipment used for the final design evaluation/competition during the testing phase of the project. As a result, all subsequent classes have had access to the evaluation system during the second week of the competition to test their designs, collect test data, and make adjustments prior to the competition.

Furthermore, after the first implementation of the RDC, faculty members became aware that the RDC criteria would need to be adjusted in future semesters due to limitations of the flow meters. The slow flow rate of 6 cc/min was not accurately measured by the Micro Motion Coriolis flow meter as desired. In Fall 2010 semester, the criteria were adjusted to 60 cc total volume, in 5 minutes, with a constant flow rate of 12 cc/min. These criteria were used for all future semesters.

The final adjustment made to the design challenge itself after the first semester was in regards to budget. Enrollment for the first semester was 10 students, so $100 per team was a reasonable budget for three teams. However, enrollment for the fall of 2010 increased to 31 students and by fall of 2012 enrollment was up to 46. The department could not sustain financing $100 for 10-15 teams. Additionally, no student teams in the first semester of the RDC implementation used the full $100. The budget for all later semesters was dropped to $25. No noticeable difference in design quality was observed after the budget decrease, and in the opinion of faculty, student ingenuity increased as a result.

Changes to the evaluation system were also made after the first semester of the RDC. Due to increased enrollment after the first semester, two new features were added to the LabVIEW/flow meter system. First, to facilitate the evaluation of 10-15 teams in the timeframe of one class period, a second Micro Motion Coriolis flow meter was added to allow for a second testing station capable of evaluating two team designs at once. The second feature added was an automatic scoring program, to eliminate the need for hand calculation of team scores and speed up the evaluation process. In addition to flow measurements, the new system allows for the input of faculty judge scores in real time, and calculates each team's final score automatically. Results of all flow parameters are combined to give a more accurate view of each team's ability to meet the design criteria given. The program displays real-time flow and time data as each team competes. The program automatically graphs flow rate over time to give students an immediate and visual representation of their design's ability to achieve the specified flow rate (see figure 3 for block diagram, figure 4 for user interface). Team performance results and faculty judge results are combined (with performance results weighted two times more than judge scores) to produce each team's final score. Additionally, the output screen displays ranked team scores as they are calculated so teams know immediately after judging how they performed, and other teams know what score to beat, which creates excitement during competition.

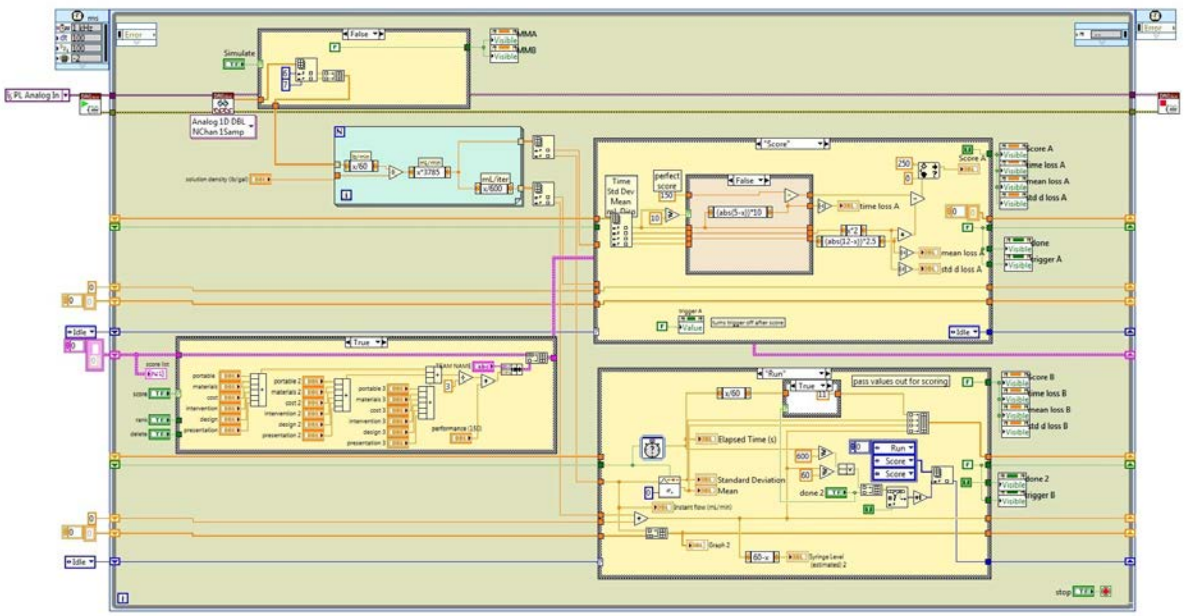

Figure 3: NI LabVIEW RDC evaluation program block diagram

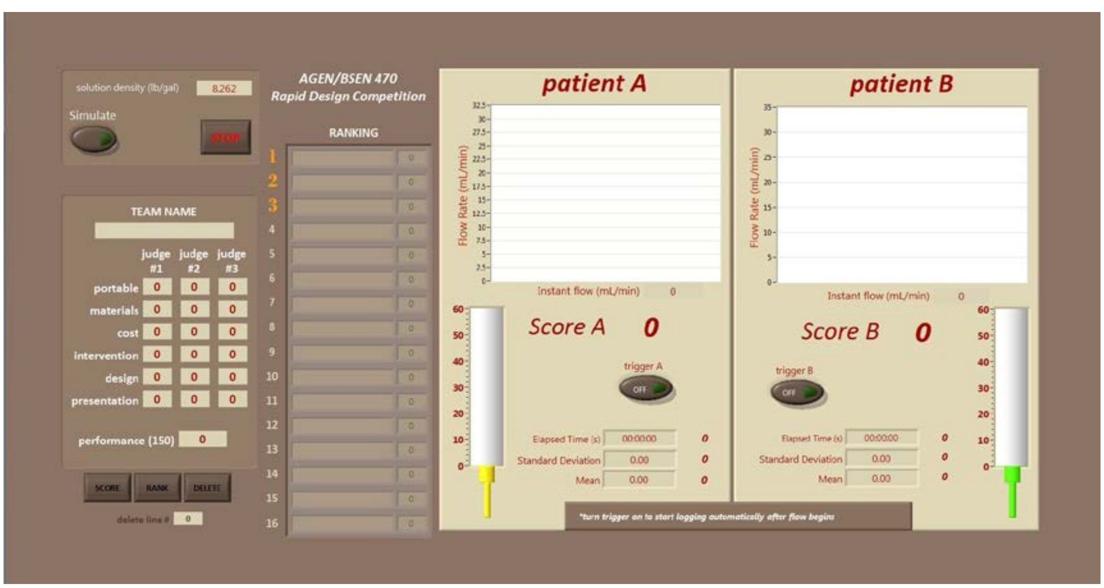

Figure 4: NI LabVIEW RDC evaluation program user interface ("front panel")

Assessment & Accreditation

In 2011 our department underwent an ABET review. For the review, the department conducted an extensive review of all required courses with respect to the achievement of student outcomes assessed using Bloom's taxonomy[6,7]. The AGEN/BSEN 470/480 sequence was assessed, including the implementation of the RDC. Because senior capstone design is split into two semesters with two course numbers, each semester was evaluated separately. With capstone projects completed over the course of two semesters, little tangible work is submitted in the first semester. To effectively assess the achievement of student outcomes, tangible student work is required. Without the RDC the results of the assessment for the first semester of capstone design (470) would have been minimal. However, because the RDC is a complete design project, from the creation of a problem statement through the completion of a final design with multiple benchmarks along the way, the assessment of the first semester of senior capstone design exceeded expectations for the majority of student outcomes.

An additional metric used in the departmental assessment was capstone design client surveys. Surveys from 1999-2005 highlighted a need to improve student communication skills, business skills, and teamwork. However, client surveys evaluated for our 2011 ABET review (from 2006-2011) showed no deficiencies in any of theses areas or any additional areas. While we cannot say with certainty if the improvement to student skills was a result of RDC or other factors, student surveys suggest that RDC played a role in this improvement.

Ability of the RDC to Address Capstone Challenges

Another objective of the student surveys was to determine if the RDC actually addressed the nine challenges that were identified relative to senior capstone design courses. Taking each challenge in order from above:

1. <u>Atypical course format:</u>
   The RDC was implemented to help familiarize students with the capstone course format in just two weeks. From the student surveys, 50% of students said they had better expectations for senior design and the overall design process format. One student said "The challenge was a good intro to what's to come on a bigger scale".

2. <u>"Unfulfilling" first semester:</u>
   The RDC allows students to see a project through to completion, giving them a feeling of accomplishment while showing them the big picture in terms of their own projects. While this challenge was not explicitly addressed in the student survey, it was evident from the ABET review that students did indeed accomplish something tangible in their first semester.

3. <u>Project variety and lack of class unity:</u>
   RDC provides the whole class with a more traditional project experience in the sense that everyone works on the same project. This is especially important in our situation where we are dealing with students from two majors, in six emphasis areas. The RDC also provided an opportunity for students to get to know their classmates in a fun interactive

environment, evidenced by student comments such as: “I also feel like I got closer to the students in my class (not just my group). This project served as common ground for all of us to bond over”. We believe this was such a subtle benefit that many students did not even realize they were bonding with their fellow students.

4. <u>The trap of iterative design:</u>
The RDC takes students through each phase of the design project with frequent deliverables. The assignment schedule forces students to progress through the design process and not get hung up on any one phase for too long. Sixty percent of students reported that they got hung up briefly in one phase of the design, with 42% wishing they would have spent more time considering their design options and 19% wishing they would have dwelled less on their design options and gotten to design testing sooner. As a result, 73% of students reported an improvement in their time management skills as a result of the RDC. An unexpected point that 48% of students reported was the realization that “sometimes things fail” and that, for many, the need to pick themselves up and move on was a lesson learned.

5. <u>Introduction to the complete design process</u>:
The RDC, while brief, gives all students a foundation on the major steps in the iterative design process. This design background becomes their model when approaching their capstone project. From surveys, 65% of students reported that as a result of the RDC they were better prepared for the design process, including spending time on each step/deliverable along the way. One student said, “Our team will model our design process off the mini-assignments required for the rapid design challenge”.

6. <u>Slow paced, nontechnical lectures</u>:
A RDC informs students of all phases of the design process in a very short amount of time and provides good examples for further elucidation in future lectures. No students commented on the style of lecture throughout the two weeks of rapid design. However, we did not evaluate whether students responded positively to the use of the RDC as examples in all subsequent lectures. Evaluating student response to the incorporation of the RDC into all subsequent lectures is an area for future work.

7. <u>Project and time management:</u>
The RDC forces students to work through each phase of the design process in a very short amount of time, and to submit assignments throughout, giving them the necessary tools to stay on track with their own projects.

   The issue of time management produced the strongest response from our students. From the surveys, 75% of students reported that finding time to meet with their group members was their biggest obstacle in completing rapid design. Yet, 96% of students surveyed completed the project according to their original schedules, and 73% reported the primary benefit of the RDC was improving their time management skills. One student said, “We stayed right on, or ahead of schedule thanks to the checkpoints that were built into the project”.

8. <u>Team dynamics in cross-disciplinary teams:</u>
   The RDC gives new teams a chance to evolve quickly. Students learn the strengths and weaknesses of their teammates and sometimes themselves, in the first two weeks of the course, rather than in the second semester. The design challenge allows students to formulate their own roles within the group before beginning work on their “real” capstone projects. The establishment of team dynamics and the evaluation of strengths and weaknesses of team members was the major benefit of the RDC for most students. From the surveys, 84% of students from the last three semesters reported that experience working with their team and establishment of member roles were what would help them most in completing their capstone project.

9. <u>Integration of faculty consultants:</u>
   The RDC required students to consult with their faculty consultant for final design approval. It was intended to be an introduction to a professor who might be new to them, and to force them to consult with sources outside the team for help. Only 15% of students reported that if they were to participate in the design challenge again, they would utilize their faculty consultant more. Yet, 60% of students reported getting stuck in one phase of the design process. Based on instructor perspective, many of the students could have been greatly aided by conferring with their faculty consultants. Encouraging or even requiring more contact with faculty consultants is a point that needs future work.

Future Improvements and Direction

While the four semesters of the RDC have been successful, there are several planned improvements to implement based on the student surveys, student comments, and observations by instructors and faculty consultants.

From the surveys, 42% of students said that if they could participate in the RDC again they would conduct more research and do more calculations, and would rely less on trial-and-error. Some students went so far as to say that they tried to perform calculations, but the variability of the provided syringes and the variability in the testing equipment made their calculations irrelevant. Variability in the testing equipment is an area that needs to be addressed. More consistent placement of the devices relative to the flow meters will help address variability in the pressure head and will be implemented in the next semester. Other students stated that they did not even consider calculations, but jumped straight to trial-and-error. Jumping straight to trial-and-error may be attributed to the two-week time limit, how the challenge was presented, or simply a lesson that students need to learn before beginning work on their final capstone projects. Regardless, this lack of engineering analysis is an issue that will be evaluated further with improvements to the exercise, in particular, by requiring calculations as a part of assignments and possibly more stringent requirements for teams to meet with their faculty consultant throughout RDC and not just for sign-off prior to construction.

Another area for improvement is the consideration of other design problems for the RDC that encompasses the diverse emphasis areas of the students in the UNL capstone course. The development of additional, applicable design problems with easily definable criteria and constraints that can be fully realized in two weeks for $25 is a major challenge for faculty. But as one fourth-semester student pointed out, “It was too easy to find previous students successful designs and just copy them. You need to choose a new problem”. Keeping students on their toes is a critical part of the RDC. Therefore, we are actively engaged in identifying a new problem for the RDC. However, it should be noted that no student team to date has been able to fully achieve all criteria and constraints of the current problem.

Finally, while not covered in the student surveys, we as instructors see the need to better implement learning outcomes of the RDC into all lectures throughout the two-semester sequence. While this was an original goal in the implementation of the RDC, the incorporation of learning outcomes from the RDC in subsequent lectures has not been consistent or overt. We are currently working on revising all senior capstone course lectures to better incorporate the learning outcomes from the RDC.

Conclusion

Overall, the implementation of the RDC over four semesters has been successful. The majority of the challenges faced by senior capstone design courses were well addressed through the implementation of the RDC, and the addition of the design evaluation system. This exercise helped revitalize the capstone course and ensured that all students share a common and successful design experience early on in the capstone course. A good example of the success of RDC is embodied in a student quote: “When you’re doing the challenge, you wonder what the point is, but in the end your strengths and weaknesses are exposed and you realize that it was more about the process and less about the product. Coincidently, a great process usually results in a great product”

Senior capstone design courses are a vital part of the undergraduate student experience. This course gives students real-world engineering design experience, and helps them improve oral and written communication skills, teamwork and teambuilding skills, as well as provides students experience with budgeting, product development, benchmarking, documentation, and working with clients. While the specific design challenge presented here and by Bucknell University is biological in nature, the concept of rapid design is easily implemented in any engineering course[1]. By implementing a RDC at the beginning of the senior capstone design sequence, the majority of the challenges associated with the capstone experience can be easily addressed, including challenges associated with cross-disciplinary teams.

Acknowledgements

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1041000. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1. J. Tranquillo and D. Cavanagh. Preparing Students for Senior Design with a Rapid Design Challenge. *Proceedings of the American Society of Engineering Education*, 2009.

2. J.R. Goldberg. Capstone Design Courses: Producing Industry-Ready Biomedical Engineers. Synthesis Lectures on Biomedical Engineering, Lecture #15. Morgan Claypool Publishing, 2007.

3. ABET Annual Report, Statistics: Accreditation Trends. "5 Largest Increases in Number of Accredited Programs by Curricular Area", 2006-2011, http://www.abet.org/2011-annual-report-statistics-accreditation-trends/. Accessed January 2013.

4. US News and World Report 2012. http://colleges.usnews.rankingsandreviews.com/best-colleges/rankings/engineering-doctorate-biological-agricultural. Accessed December 2012.

5. N. Hotaling, B. Burks Fasse, L.F. Bost, C.D. Hermann, and C.R. Forest. A Quantitative Analysis of the Effects of a Multidisciplinary Engineering Capstone Design Course. *Journal of Engineering Education* 2012; 101(4): 630-356.

6. A.M. Kelly, E. Curtis, J. McCoy, D.D. Schulte, and D. Jones. Application of Data Management Tools for ABET Accreditation. *Proceedings of the American Society of Engineering Education*, 2012.

7. B.S. Bloom. Taxonomy of Educational Objectives, and the classification of educational goals - Handbook I: Cognitive Domain. New York: McKay, 1956.

Appendix I

Student survey, % results (from 50 students over 4 semesters), and selected comments

1. How did your team perform? Did you stay on schedule? Why or why not?

   96% stayed on schedule
   4% did not stay on schedule

   "We stayed right on, or ahead of schedule thanks to the checkpoints that were built into the project"

   "We had multiple group meetings, so all of our major decisions were made together."

   "I believe having deadlines and multiple assignments was probably the biggest reason our team stayed on schedule"

   "The quick due dates made us push and not drag out feet"

2. What were the main challenges in completing the project?

   75% - Finding time to meet together
   50% of 1st semester students only - The inability to test their device using actual testing equipment
   31% of students from semesters 2-4 - Finding resources & staying within the budget
   19% - Inconsistency in the challenge itself specifically mechanical variation between syringes
   12.5% - Vague criteria

   "Our schedules conflict quite a bit and so our only time to meet was at night. That was really frustrating."

   "The time constraint was definitely a challenge."

   "The main challenge my team had to overcome was managing four schedules and finding time to meet."

   "Consistency of the syringe and overcoming mechanical errors in the syringes was the biggest problem for us."

3. What do you feel were the strengths of your team's effort?

   67% - Effective group dynamic, good balance of skills, flexibility, dedication, and trust
   42% - Group members stayed on task
   21% - Professional behavior of group members
   21% - Effective communication
   21% - Good design planning

"Group discussions were effective and we ended each meeting with a clear plan of what needed to be done next."

"I feel like the time, effort, and thought devoted to the project was outstanding by all members. We got together right away and met quite often after that."

4. What do you feel were the weaknesses of your team's effort?

   75% - It was difficult to coordinate schedules
   23% - Poor group communication
   17% - Lack of drive towards the end
   10% - Didn't seek outside advice from their faculty advisor

   "Lack of communication was our biggest problem. It's not that we didn't meet up and discuss our project, but it appeared that we were doing more talking, rather than listening."

   "We didn't ask for help/advice from our faculty advisor other than for the assignment. I truly think we missed out on a great resource there and wished we hadn't, lesson learned."

5. If you were to do it again, what would you do differently with regards to your team's process?

   42% - More time considering/deciding upon a final design
   42% - Should have done more calculations and engineering analysis
   38% - Should have tested the device more
   19% - Less time dwelling on design selection & more time building and testing
   17% - Needed better delegation of tasks and time management

   "We had a lot of creative ideas we wanted to try, so deciding on a design took too long. We didn't have as much time to build and test as we wanted."

   "I would allocate more time to the building and testing of our prototype."

   "We relied too heavily on trial and error and forgot to use our engineering background."

   "Honestly, I wouldn't change a whole lot with our process. We got the results we wanted, and were able to enjoy the project, compete, and win."

6. Reflect on your own individual role in the project?

   This question was not evaluated for course improvement, but meant to be reflective for the student's benefit.

7. What were the strengths of the design challenge exercise as it was presented and defined?

   66% - Quickly established group dynamics

50% - Manageable steps to facilitate time management
48% - Well-defined project and established criteria
48% - Helped establish expectations for senior design & overall design process
25% - It was challenging
21% - Students were treated as adults and given complete project control

“The challenge was a good intro on what’s to come on a bigger scale.”

“I also feel like I got closer to the students in my class (not just my group). This project served as common ground for all of us to bond over.”

“We found out a lot about our group in a very short amount of time.”

“It was fun to compete!”

“This challenge offered a real-world example of engineering instead of theoretical examples of engineering. This taught us a lot about how things actually work when it comes to physics, statics, fluids, and dynamics.”

8. How could the design challenge be improved in the future?

80% from 1st semester only – More defined guidelines for judging and presentation evaluation
50% of 3rd semester only students – Testing and actual competition parameters should be the same
40% from 1st semester only – Access to testing facility and equipment
30% from semesters 2-4 – Less variability in the testing equipment
23% - Different challenge
6% - Access to a workshop for device construction
3% - Require calculations

“Overall though, I’d say this was a great learning experience, and something you should definitely keep.”

“A new problem should be chosen. It was too easy to find previous successful designs.”

“The pressure head from the testing device height should be kept constant and at a pressure comparable to inside a human vein, so that it’s consistent and in keeping with the project description.”

9. What skills from the design challenge do you think will aid you in your upcoming senior design project?

84% of students from semesters 2-4: Experience with my team
73% - Time management
65% - Design process knowledge

48% - The knowledge that sometimes things fail
38% - Effective group communication
21% - Critical thinking

“Working with our specific group members under a deadline and stressful conditions will be a huge asset when deadlines arise in our upcoming senior design project.”

“When you’re doing the challenge, you wonder what the point is, but in the end you’re strengths and weaknesses are exposed and you realize that it was more about the process and less about the product. Coincidently, a great process usually results in a great product.”

“Every aspect of the RDC will aid us in our capstone project. We learned to improvise, manage conflict, remain flexible, delegate responsibility, communicate professionally, and so much more.”

“We can model our design process off the mini assignments required for the RDC.”