

'Historical' Rapid Design Challenge for Bioengineering Senior Design

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Introduction

For a number of years we have introduced students (in their teams) to the bioengineering senior design experience at Florida Gulf Coast University (FGCU) with a ‘rapid design challenge’ (RDC), inspired by a challenge reported previously by Tranquillo and Cavanagh¹. Kelly and colleagues at the University of Nebraska, Lincoln have also adopted and published recently on their own variation of this approach². Goldberg and colleagues at the University of North Carolina Chapel Hill have integrated a challenge-based approach into their biomedical engineering senior design sequence, but using design problems that run throughout a semester³. Cordray and colleagues from the VaNTH/ERC coalition have described the broader effectiveness, replicability, and generality of challenge-based instructional modules in bioengineering⁴. The senior design RDC experience here at FGCU within our B.S. Bioengineering degree curriculum has been very popular, and an effective means to jumpstarting students to more effectively working in their teams, ‘upping the ante’ on open-ended design expectations for the senior year, and giving students and teams an opportunity for early success (and failure) in a quick but intense ‘low stakes’ design challenge prior to committing to their full-scale ‘higher stakes’ senior design projects.

In the fall semester of 2013, the lead author as FGCU bioengineering senior design instructor took a different tack to the subject matter of the RDC, which previously had focused on technically simple medical device problems. A ‘historical’ theme was used where students were called upon to envision that they were biomedical engineers of the year 1900 – and their task was to design a novel electrical stimulation device to required (and at their option preferred) specifications and using only the technolog(ies) and knowledge of that time. The intent of this ‘historical’ rapid design challenge was to (i) constrain solution pathways to technologies based for the most part on simple (but perhaps elegant) principles of physics and engineering (reinforcing their knowledge and confidence from earlier coursework in physics, mechanics, circuits, and instrumentation), (ii) encourage students to use their life-long-learning skills for information searching to explore the technologies and inventions of the time (including patents), and (iii) introduce a different and thought-provoking ‘fun’ twist to an already successful RDC process. This approach also opens up a wide range of new RDC themes for each academic year.

This paper reports on the details and outcomes of this ‘historical’ rapid design challenge format for bioengineering senior design, including faculty and student perspectives and lessons learned.

A Rapid Design Challenge To Jumpstart The Bioengineering Senior Design Experience

The rapid design challenge described here occurs in the first few weeks of an overall senior design experience in bioengineering at FGCU that is a two-semester sequence (in the fall the 2 credit-hour BME4884 Bioengineering Senior Design I, and in the spring the 2 credit-hour BME4885 Bioengineering Senior Design II). The preceding junior year in the B.S. Bioengineering curriculum includes foundational design courses that include EGN3641C

Engineering Entrepreneurship (3 credit hours), EGN3433C Design for Manufacturing (2 credit hours), and BME4800C Bioengineering Product Design (3 credit hours).

The schedule for BME4884 Bioengineering Senior Design I initiates with team formation and the rapid design challenge, then assignment of teams (of two to four students) into their full two-semester design projects (typically with clients in local industry and/or health care), and through the remainder of each fall semester progresses teams through the design process (including problem definitions, team mission statements and contracts, development of project Houses of Quality including competitive benchmarking, pertinent FDA regulations and engineering standards, patents and intellectual property, and structured brainstorming leading into project design solution concepts and selection). The course also includes aspects of professional development, and post-graduation planning. A roundtable design review late in the semester leads into the two main deliverables for the first semester – a team portfolio of all work accomplished (up to the point of selection of a lead design solution strategy) along with a team poster presentation (open to the program faculty and staff). Learning outcomes for this course include those focused on application of technical and engineering design skills and professionalism, and also refinement and demonstration of effective communication skills via design documentation and presentations. In the second semester of bioengineering senior design, teams carry their work forwards through engineering analysis, prototyping, and testing with multiple design reviews. Ethical considerations including risk-benefit, human factors, potential global and societal impact of design solutions, aspects of manufacturing and costing, design for the environment including product life-cycle, and protection of potential new intellectual property are also included. This second semester of bioengineering senior design culminates with teams preparing comprehensive design portfolios and with team presentations in an open-to-the-public (including project clients and mentors) poster forum and celebration.

A rapid design challenge has been included at the initiation of our bioengineering senior design experience each year since the fall of 2009. This approach was originally modeled after the work of Tranquillo and Cavanagh at Bucknell, who described their methods and experiences with a biomedical engineering senior rapid design challenge requiring design and build of “a device for a third-world clinic to infuse a cholera treatment solution” (and subject to multiple constraints and performance metrics)¹. Our goals with this version of a rapid design challenge (which to date has focused on various versions of relatively simple medical device designs) have very much included those stated by Tranquillo and Cavanagh; namely, that each annual problem should “(1) be of interest to students, (2) have a solution that is technically simple enough to be built in a short amount of time, (3) allow for many types of viable solution concepts, (4) have a high probability of success in the allotted time limit, and (5) be presented in such a way as to create an environment where healthy competition is rewarded and risks and creativity are encouraged.” In addition, we have used the rapid design challenge to introduce students to working in their teams (which usually are kept intact after the rapid design challenge is completed and as students take on their full-scale senior design projects) and team dynamics, as well as to introduce students to the documentation and presentation expectations in senior design.

The ‘Historical’ Rapid Design Challenge

For the fall semester of 2013 a new direction was introduced to the senior design rapid design challenge – that of adding a constraint that the problem to be addressed and solved was set in the year 1900 and that the only resources and knowledge that could be brought to bear had to be of that time period. As described earlier, our goal with this new version of the design challenge was not only to introduce an unusual and hopefully fun ‘twist’, but also to encourage students all the more to consider and use simple approaches to their solutions and prototypes (ideally drawing upon their knowledge and skills from earlier coursework in physics, mechanics, circuits, instrumentation, etc.). We were also intrigued to see if students would make use of their life-long-learning skills for information searching to explore the technologies of the time (including patent searching), which was an option but not requirement for them. The specific problem assigned was within the context of bioelectricity and electrophysiology, and was conveyed as follows.

- Problem Statement -

Imagine that it is the year 1900 and you aspire to design and use an electrical stimulation device that can reliably produce single pulses of ‘rectangular’ milliamp level currents through resistive loads on the order of 1 kOhm and for controlled durations on the order of a millisecond. By ‘rectangular’ we mean a current that is quickly switched from zero, up to some constant amplitude, and then back to zero. Design, build, test and document such a prototype device according to the following constraints and specifications.

The device:

- Must be powered by a constant voltage of 12 V or less (to mimic the simple batteries of the time).
- Can utilize wires, resistors, capacitors, and/or simple mechanical switches.
- Can make use of simple principles of mechanical clocks or timer mechanisms of the time, as well as principles of Newtonian mechanics (Newton’s Laws of Motion were published in 1687!).
- Cannot use electrical actuators (e.g. electric motors, electromagnetic switches),
- To meet a basic test specification, should safely produce a single 1 mSec rectangular pulse of amplitude 1 mAmp through a 1kOhm resistor (test load which mimics the impedance of living systems).

While it is not a requirement of the Rapid Design Challenge (RDC), it is desirable that the design be able to be controlled so that additional amplitudes and pulse durations can be produced (in the same range as the above test spec; for example, durations of 1, 2, 3, 4 mSec etc. and amplitudes of 1, 2, 3, 4 mAmp etc.) It is desirable that the total expense for materials, parts, etc. needed by each team to prototype and test their designs not exceed \$20. In any case, students will not be reimbursed ... for expenses exceeding \$20 per team. Teams have at their disposal the resources and stock supplies of (the college).

This project will be carried out in teams of two or three; as possible these will be the same teams you will work in throughout Bioengineering Senior Design I and II. This project is a “challenge”

to do your best job (using your existing design, engineering and technical, creative, and communication skills) in:

- rapidly designing,
- building (at least as a functional prototype),
- testing (at least to verify that the requirement of meeting the basic test specification can be achieved), and
- documenting (on an RDC poster) your device.

The schedule for the challenge this year was as follows (Table 1) and included only two weeks of work (in other years we have allotted as much as four to five weeks), starting up in the second week of classes.

Table 1. Rapid Design Challenge Schedule And Deliverables As Conveyed To Students In The Fall 2013 Semester.

Date	Topic	In-Class	Deliverables Due
26-Aug	Team Formation; Rapid Design Challenge Initiation	Launch RDC Initial Project Planning	None; but initiate drafting of Customer Needs, Target Specs & Metrics; time permitting Brainstorming on Design Concepts & Approaches
2-Sep	Labor Day Holiday, but keep the work progressing!	No Class Meeting but Teams Schedule a 15 minute “Check-In” with Dr. X on the Tuesday or Wednesday	Due for upload (by 5 pm on Wed. Sept. 4) are Problem Statement, Customer Needs, Target Specs & Metrics, Concept Classification Tree or Fishbone Diagram
9-Sep	Rapid Design Challenge Showcase with Posters (Print posters by the Friday 9/6)	RDC Posters with Prototype Design Demonstrations (posters must <u>document performance in meeting specs</u>)	Posters; also design notebooks

While baseline content of the RDC poster was specified by the instructor, teams were otherwise challenged to make use of and document their best skills in engineering, design (including prototyping and testing) and presentations as drawn from prior coursework. Subsequent to the “Rapid Design Challenge Poster Showcase” where teams presented their designs and results to the dean of the college, and program faculty and staff, the course lead instructor in a later class

period reviewed and summarized the overall achievements of all teams in meeting the RDC requirements and preferences, recognizing special successes and strategies. This class meeting also included a roundtable discussion with the entire class on individual and team reflections from the RDC. Students were asked prior to this open discussion and celebration of the RDC to write and submit a one to two page individual essay describing up to five lessons learned via the RDC. Lessons learned could be “any aspect of the RDC project that could give each team and/or team member an improved perspective or plan for the year’s full senior design project.” Interested students were also referred after the challenge to an excellent published review on actual designs and approaches to solution of the RDC problem in the time period around and leading into the year 1900⁵.

Outcomes, Assessment, and Evaluation

The nineteen students registered for Bioengineering Senior Design I in the fall semester of 2013 were organized into seven teams (of two or three students) for the rapid design challenge. By the completion of the challenge for the poster presentation showcase, all seven teams had arrived at at least one functional prototype (and several teams had explored multiple prototype strategies). All prototypes fairly met the challenge requirements in terms of power supply, and simple components and principles of the time period (including exclusion of electrical actuators). Solutions included many of those to be expected for making a quick and reliable electrical contact (conductive balls or rods rolling down a variable inclined ramp or tube and striking contacts to make and then break connection through a circuit with one or more fixed or variable resistors) as well as some creative spring-loaded designs (including a mousetrap!) and one very innovative design incorporating a photo-flash and photo-diode. For this latter design, the student team appropriately documented invention and patenting of various photodiode designs at and prior to around 1893. Special recognitions were made by the instructor to teams with an especially impressive calibration curve for pulse duration control, a team with the most rigorous test data set on reliability meeting the main test specification (1 mA through 1 kOhm for 1 mSec), and a special ‘innovation’ award for the team with the photodiode approach.

Seventeen of the nineteen students submitted the requested personal reflections essays, listing up to five ‘lessons learned’ each from the RDC experience. For assessment and evaluation of the immediate impact of the RDC, ‘lessons learned’ as reported by each student were compiled into a spreadsheet and then organized into main categories. Table 2 conveys the frequency of student responses for each main category (from most frequent to least), along with sample quotes from students. Not surprisingly, the truly rapid nature of the challenge reinforced in over half the students responding (categories in Table 2 with 9 or more responses) the immediate importance of project time management and planning (88% responding); team skills and responsibilities (76%); communication skills (59%); knowledge and use of engineering, math and science (59%); skills in prototyping, testing, and design iterations (53%); and the importance of brainstorming, concept generation, and concept selection (53%). Less frequent and likely more individual responses were in the areas of poster preparation and presentation skills (24%) project budgeting and costing (18%), and hands-on technical skills (6%) (all areas where most of our students are typically very well prepared prior to senior design). The unique constraint of this new ‘historical’ rapid design challenge was appreciated by two students (12%), although this was not really intended to serve as a ‘lesson learned’.

Table 2. Categories, Response Numbers, and Sample Quotes from Students on Immediate ‘Lessons Learned’ from the Rapid Design Challenge

Category	Response #	Sample Quotes
Time Management and Planning	15	“crucial to keep goals and deadlines in perspective... this was the first project where my partner and I made realistic timelines in order to account for unexpected problems” “I feel that I could have persuaded the group (including myself) to make a schedule for the project and stick to it”
Team Skills	13	“compartmentalize tasks to everyone’s strengths. We worked much more efficiently once we designated everyone certain sections and everyone knew what they were responsible for” “for the upcoming project, we need to organize our roles from the beginning to ensure we complete our milestones on time”
Communication Skills	10	“communication is one of the key aspects to being successful in this project” “communication is essential to finish and complete the ideas”
Knowledge and Use of Engineering, Math, Science	10	“one thing that I took from this project was a better appreciation for the subjects covered in our bioengineering curriculum” “real, in-the-moment experiments will never be exact to what was expected based on the theory”
Skills in Prototyping, Testing, and Design Iterations	9	“as a team we learned that changes in prototype design may be inevitable” “simple changes or small errors that are overlooked can make the difference”
Brainstorming, Concepts, and Solution Selection	9	“I feel that my group put forth great brainstorming ideas to come up with an “out of the box” idea along with a backup project” “early brainstorming is the key to getting the project going”
Poster and Presentation Skills	4	“... related to our poster and presentation. I learned that having some early feedback can help us correct and/or add elements” “a presentation poster does not have a lot of space... had to trim down my section several times”
Budgeting and Costs	3	“I learned how to save money on building materials while on a tight budget” “another lesson learned in the process was to take care of our budget”
Appreciation of Unique Constraints	2	“unique problem of building our own solution to a 1800’s technology posed an interesting case” “stipulation of using pre 1900 technology made me think how hard inventors and scientists had to think outside the box to prove theories and invent ... technologies”
Hands-On Skills	1	“interesting lesson that I took away from the RDC was becoming more comfortable with biomedical equipment”

An additional indirect assessment of students' assessment of RDC impact in jumpstarting their senior design experience was carried out in February of 2014 (six weeks into the second semester of senior design) in order to compare longer-term perceptions of the RDC value versus those from the reflections essays carried out just subsequent to the challenge. Eighteen students responded to this anonymous survey. Students were provided with the categories listed in Table 2 and asked to indicate as many as five (or at their option fewer) areas where they felt that the RDC "provided significant value to you and/or your team as you initiated the senior design experience." Highest rated categories were: knowledge and use of engineering, math and science (67%); skills in prototyping, testing, and design iterations (67%); the importance of brainstorming, concept generation, and concept selection (67%); team skills and responsibilities (61%); and time management and planning (56%). Value placed on poster preparation and presentation skills increased to 44% (in comparison to 24% in the early reflections essays), perhaps through some students recognizing that their end-of-semester poster presentations in December had benefited from the RDC experience. Value placed on the RDC lessons in the unique constraints of the RDC rose to 50% (from 12%) and hands-on technical skills value rose to 39% (compared to 6%). Value placed on the RDC experience with communication skills fell somewhat to 33% (from 59%) and budgeting and costs remained about the same at 17% (compared to 18%).

Discussion and Conclusions

Overall, introduction of a 'historical' theme to our bioengineering senior rapid design challenge this year appears to have been a success, with all teams arriving at functional and tested prototypes – and with a range of interesting and fun solution strategies. The constraints introduced into the problem statement also successfully motivated students to pursue relatively simple and achievable designs, while leaving the door open for teams to still pursue especially creative ideas. Since it was not a requirement of the RDC that teams carry out literature and/or patent searches into the time period and content of the RDC problem, only a few teams spent significant time in these areas. In hindsight this is understandable given the very tight timeline that was imposed this year (only two weeks). An advantage to running such a design challenge over such a brief period of time is that it can be completed quickly with still substantial student 'lessons learned' without overly subtracting from the time students in their teams have to launch into their full two-semester senior design projects. To quote from one student's reflection essay:

"The Rapid Design Challenge for this year was very unexpected and fast paced... There were several things that I learned from this project and I'm grateful to have had this experience to get me ready for the final senior design project."

In terms of student 'lessons learned', this rapid design challenge had clear impact (both immediate and longer-lasting) on many students and their teams in recognizing the importance of and iterating on their methods for project time management and planning, and with team skills (roles and responsibilities, dynamics, etc.). Students and teams also valued the RDC experience in various aspects of 'getting the rust' off of their engineering and design skills – being sure to use their knowledge of engineering and science, practice with brainstorming and concept generation and selection, as well as with prototyping, testing, and design(s) iteration. To quote another student:

“Overall this project was a very demanding and challenging scenario that allowed me and my teammate a headfirst dive into senior design while allowing us to flex our critical and creative muscles.”

The ‘historical’ theme introduced into our bioengineering senior design rapid design challenge this year potentially also opens the door to a host of new challenge problem themes in future years not only here at FGCU but also at other institutions that have or will adopt this or similar methods. As Kelly and colleagues have noted for their rapid design challenge, “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”². Cracking open the vast history of scientific exploration and invention of medical devices and technologies should readily yield numerous fun yet challenging design themes for students in our field.

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