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An Engineering Design-Oriented First Year Biomedical Engineering Curriculum

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An Engineering Design-Oriented First Year Biomedical Engineering Curriculum

Abstract

In this paper we will report on the development and deployment of a new, integrative, first-year biomedical engineering curriculum focused on studio-based learning of engineering design. Developed by an interdisciplinary team of faculty and staff, this curriculum is team-taught (meaning, multiple faculty are in the studio at all times) by biomedical engineers, mechanical engineers who specialize in design, a professor of English, a computer scientist, and a mathematician. The foundation of the curriculum is the engineering design studio, which meets four hours per day, four days per week. The design studio has a different general theme for each academic quarter – for example, the Fall quarter theme is 'Play for All,' focusing on children's play environments, toys, and games that are universally accessible. Within this theme, students complete multiple design projects through the prototyping phase (e.g., redesigning the 'popcorn popper' walking toy for children with a range of physical abilities and sensitivities), accompanied by a range of documentation (e.g., empathy maps; engineering drawings; written, poster, and oral presentations). Traditional first year curriculum places an emphasis on sound engineering fundamentals and does not, in our opinion provide enough room for the application of said concepts. This paper introduces a new practice-driven biomedical engineering curricula, and will report results of qualitative research on student and faculty/staff reactions to the new curriculum as the first year progresses. This paper will also report initial quantitative data on the academic hardiness of the biomedical engineering students: Were these students measurably more 'academically hardy' than other incoming engineering students? Did the repeated exposure to open-ended problem-solving situations measurably increase these biomedical engineering students' academic hardiness? Finally, we will present a comparison of the academic performance of students who participated in this new curriculum with students who did not.

Introduction

The engineering design studio was created by a group of faculty who wanted to integrate design, writing, professional responsibility, and engineering topics into a multidisciplinary studio setting. Traditionally design studios are associated with architecture and industrial design.

> "In studio, designers express and explore ideas, generate and evaluate alternatives, and ultimately make decisions and take action. They make external representations (drawings and three-dimensional models) and reason with these representations to inquire, analyze, and test hypotheses about the designs they represent. Through the linked acts of drawing, looking, and inferring, designers propose alternatives, and interpret and explore their consequences. ... They use the representations to test their designs against a priori performance criteria. And in the highly social environment of the design studio students learn to communicate, to critique, and to respond to criticism, and to collaborate."[1]

It is not unusual for design and analysis activities to be separated in an engineering curriculum. Communication of the design is often given secondary status rather than being seen as important during the design process itself. Social and environmental factors are often only considered after the design is finalized and changes become difficult to implement and expensive. The faculty members wanted to create a more integrative approach to design that considers broad perspectives at the beginning and throughout the design process.

Biomedical engineering students are particularly well-suited for the studio approach because of the integrative nature of biomedical engineering. Students have at least considered that their discipline will require the blending of concepts from engineering, biology, and medicine.

We hypothesized that students who complete the new design-oriented first-year biomedical engineering (BE) curriculum will become more 'academically hardy' – possessing the "ability to persist and succeed academically in challenging situations" [2] – as measured by the Revised Academic Hardiness Scale (RAHS) [3]. The RAHS is a multiple-choice survey which asks students to self-report the level of veracity (using ratings of 1=Completely False, 2=Mostly False, 3=Mostly True, 4=Completely True) of statements regarding commitment, control, and challenge (e.g., "I enjoy the challenge of taking difficult classes.") Hardiness has been positively associated with reported academic self-worth [4] and completion of training programs [5] and curricula [6], and hardiness was identified by the faculty crafting the curriculum as a desired attribute of both students within the curriculum and alumni of the curriculum.

Curricular Structure

At the heart of the new curriculum are three design studios. The first studio is an 8 credit hour course. It meets 4 days a week for 4, 50-minute class periods a day. The studio integrates typical freshmen courses that include design process, graphical communications, and rhetoric and writing. Each studio is focused around both individual and team design projects and support a theme. The theme for Studio One is "Play for All." Individual projects for Studio One include machining a top, performing an ethnographic analysis of a practicing engineer, and producing a fidget spinner for a client of the student's choice. Team projects include an ethnographic study of a playground, reverse engineering a child's toy and finally designing a toy for a not-for-profit that has a lending library of toys for children with disabilities. Studio One is team taught by a humanities faculty and an engineering design faculty.

The theme for Studio Two is "Work for All." Studio Two is a 6 credit hour course that meets 4 days a week for 4, 50-minute class periods. In Studio Two, introduction to circuits, computer science, and technology and society topics are combined. The primary client is a not-for-profit that maintains a commercial laundry for adults with disabilities. Students collaborate in teams to identify and prototype ways to improve the work of an individual associated with the commercial laundry. Studio Two is team taught by humanities, biomedical engineering, software engineering, and design faculty.

The theme for Studio Three is "Create Value for All." Studio Three is a 6 credit hour course that meets 4 days a week for 4, 50-minute class periods. The technical topics of introductory electrical engineering, computer science, and technology and society are developed further. Students are required to use their new skills in electrical engineering, computer science, and technology and society to propose and deliver projects that incorporate technology as well as consider the impacts of their projects. Studio Three is team taught by humanities, biomedical engineering, software engineering, and design faculty.

Example Integrated Experience

Studio One

The final project in Studio One required a team of students to create a toy for a child with disabilities. We partnered with a local charity, Reach Services, who maintains a lending library of toys for children with disabilities. Parents, teachers, and therapists can check toys out of the library to use at home, in school, or in therapy sessions. The final project consisted of three phases: an innovation tournament, concept development, prototype development and presentation.

The innovation tournament will be discussed here. The learning objectives for the innovation tournament were as follows:

1. Identify the value proposition of a product or service from the point of view of stakeholders.
2. Articulate the criteria that yield an effective pitch.
3. Outline a process for developing elevator pitches.
4. Implement strategies for developing elevator pitches.
5. Practice giving a pitch to a client.

The innovation tournament required students in the class to develop an elevator pitch that explained their idea for an appropriate toy for the lending library. All 52 ideas, one from each student, were pitched to the class. Afterwards the class, faculty, and staff of the studio voted on the top 26 ideas. Students who had their idea selected for the top 26 were allowed to pick another student in the class to help them pitch their idea to the client. The client came and listened to all 26 pitches. Afterwards, the client picked the top 12 to be prototyped. Students who had their ideas selected by the client were responsible for forming a team and making their idea a reality.

Students used the Elevator Pitch module developed by KEEN to craft their pitches. [7] A rubric is supplied with the module to be used when evaluating student pitches and is shown in Figure 1. Faculty evaluated each student as either poor, below average, average, above average, or outstanding in each of four categories. For example, faculty evaluate students on their ability to make an argument for exigency.

Student performance varied from ratings of “1” to “5”. In general, students performed best when making an argument for exigence. (Average of 3.6 – Standard deviation of 0.82) Out of 50 students, no students were given a poor rating in making an argument for exigence. There were 4 students rated below average, 18 students rated average, 21 students rated above average, and 7 students were rated outstanding. Students were the most inconsistent when providing a clear path to move forward. (Average of 2.8 – Standard deviation of 1.15) Ratings ranged from a poor to outstanding. There were 9 students who were given a rating of poor, 10 were rated below average, 17 were rated average, 11 were rated above average, and 3 were rated outstanding.

Faculty members felt that requiring freshmen to pitch their ideas to a client was an excellent opportunity for students to practice persuasive argument under pressure, and was a useful skill both while in college and after graduation.

Rubric for Assessing E-Learning Module Outcomes **Module: The elevator pitch: advocating for your good ideas**				
Assess each student's level of attainment of the selected outcomes. Use the following rating: **1. Poor:** Shows little or no progress in achieving the outcome **2. Below Average** **3. Average:** Shows evidence of progress in achieving outcome that reflects a merely acceptable level of mastery. **4. Above Average** **5. Outstanding:** Shows evidence of progress in achieving outcomes that reflects superior mastery.				
Student ID	Made an argument for exigency	Provided a non-technical explanation of the solutions	Clearly stated a value proposition	Provided a clear path to move forward

Figure 1: Elevator Pitch Rubric for Student Presentations

Studio Two

In Studio Two, students worked with a local not-for-profit that runs a commercial laundry. The laundry hires people with disabilities to do the work. The not-for-profit company provided training for our students on how to interact with people with disabilities and the HIPAA requirements that must be followed. This training gave our students insight into the type of training that they will receive after graduation. The not-for-profit provided us with a list of individuals who had various needs. The faculty formed student teams and asked the teams to indicate their interest in the listed needs. Teams were assigned to individuals. Teams then went to the laundry to observe and interact with their individual client. One thing that the teams noticed was that simply observing some clients altered their normal work patterns. Some clients worked much harder when the team was observing, and other clients had difficulty concentrating. Student teams were able to talk to job coaches and case workers to get additional insight; however, determining stakeholder needs was quite difficult.

In addition, most clients said that they liked everything that the students proposed. Teams made every effort to tailor the process to meet the needs of an individual client. Some clients were cognitively able to look at three options and give feedback to the team about what they liked. Other clients were only able to consider one option at a time and give feedback. Several clients indicated that they liked everything the students proposed equally. Students relied on additional information from job coaches and case workers to try to make informed decisions.

Because of the relationship that student teams developed with their individual clients, they found their projects rewarding. One group reported that their client cried she was so happy when they presented her with their solution. For another group, when they took a rough prototype to their client to get feedback before making the final design, their client asked to keep the rough prototype until the group could return with the final design. The client felt that the rough prototype made her more productive and did not want to lose that productivity.

Students were encouraged to look for existing solutions to client problems before making anything from scratch. Interestingly, students who found existing solutions felt that they were somehow “cheating”. Our reassurances that using existing solutions is perfectly appropriate did not dispel this feeling.

Studio Three

In Studio Three, students were allowed to propose their own designs. The only requirements were that the design must

1. include sensors and programming,
2. cost less than $100,
3. and be doable in eight weeks

Four of the eleven groups returned to toys that they produced in the first quarter. They wanted to improve the users’ experience with added features. The remaining seven groups proposed projects from a variety of areas: one group worked on an project for a third world country, one group looked at determining thyroid levels, one group developed a warning system for a faculty member’s research, one group looked at developing a device for physical therapy, one group worked with an ME Capstone Design group, one group adapted a workout device for athletes, and one group developed a toy for college students.

Students were required to write an in-depth proposal for their project. Their writing ability showed marked improvement along with their ability to express the social, environmental, economic, and ethical aspects of their designs.

Results to Date

Academic Hardiness Results

RAHS results indicated that biomedical engineering (BE) students (n = 43) were not more or less ‘academically hardy’ than other incoming engineering (non-BE) students (n = 34). This baseline measure gave some confidence that any follow-up assessments may measure acquired differences between BE and non-BE student populations, rather than innate differences. The first follow-up assessment is scheduled for May of 2018. One possible concern for the follow-up assessment is that although we hypothesized that repeated exposure to open-ended problem-solving situations would increase our students’ hardiness, for some assessment items, there is little room for results from either student population to increase. For example, 100% of both BE and non-BE student populations reported “Mostly True” or “Completely True” for “Doing well in school is as important to me as it is to my parents,” and “I take my work as a student very seriously.” We may therefore examine results on the subscale level (e.g., examining items that purport to measure commitment separately from items that purport to measure challenge or control [8]), or may supplement the RAHS with another measure designed for and/or validated on populations expected to be persistent in challenging situations [5]. Alternatively, our original hypothesis may not be supported by the data. It is conceivable that academically-talented incoming students, used to excelling in high school courses, would feel confident and resilient as they started their first year of college. During the first year of study, these students experienced academic challenges that (in some cases severely) tested their confidence and resilience. Students (both BE and non-BE) likely now have a better idea of how much they do not yet know, and how hard they will need to work to succeed academically. As a result, they may report feeling less 'academically hardy' and more fragile than they did when entering college. If the May 2018 data indicate that this may be a possibility, we will continue to use the RAHS and re-assess the hardiness of these students as they enter and leave their second year of study.

Qualitative Information

Student Perspectives: Student perspectives are summarized from multiple sources: Institute end of quarter evaluations, a focus group conducted by Institutional Research, Planning, and Assessment, and informal plus/delta surveys. In plus/delta surveys, students are asked to list things that they like about the class and things that they feel can be improved.

Students were excited about the projects and the hands-on nature of the course. They expressed pride in the experiences that they had that were different from the upper level BE students; however, as they began to compare their experiences to the rest of the freshmen on campus, they felt that they were working too hard. The studios give students a lot of freedom in deciding when to complete which activities. This lack of structure caused some students to fall behind and to spend unusually long amounts of time completing their work at the end of the quarter. Students acknowledged that they had learned a significant amount of work, but they felt that the learning was too painful. Currently, they express pride and pain that they have the hardest curriculum on campus:

> There's no refuting the fact that I learned a lot in this class. I learned the basics of Solidworks, how to conduct and gain useful information from ethnographies, how to create engineering drawings, how to work in the machine shop, how to work well in teams, how to give an elevator pitch, and many other things. However, the pace at which I learned them was grueling.

The ambiguous nature of design was problematic for some students. These students wanted a recipe that told them exactly what they needed to do to obtain an "A" in the course. Comments from the focus group included:

> Regarding course goals and assignment expectations, students in ENGD-01 expressed a lack of understanding. Students in ENGD-02 echoed this, expressing confusion about the expectations and timeline of the winter project. Students encouraged instructors to be more specific when discussing instructions and expectations.

Students developed good relationships with the course faculty and technicians:

> The professors are amazing, willing to help, and completely devoted to the studio course and all of the students in the course.

They appreciated the faculty dropping by their workspace and giving suggestions. In addition, they developed a good relationship with the staff from the studios. The students also seemed to bond more than a typical freshmen class. They routinely helped each other with projects and were encouraging to their peers. They occasionally developed “group think” and got sidetracked on issues.

Faculty and Staff Perspectives: Faculty acknowledge that freshmen students may have been given too much freedom. The next iteration of the studio will address implementation of hard deadlines and monitor student progress more closely.

Faculty and staff developed close relationships with the students. They contacted students when they were ill and had the ability to take students aside for mini-conferencing if the student seemed to be struggling. The close relationships were rewarding for both the faculty and staff.

Faculty noted that most freshmen expected to have high GPAs in college. Receiving an average grade of “C” on a single assignment was devastating for many of the students. Students who focused on getting an “A” in the course struggled more than students who focused on meeting stakeholder needs.

Faculty were able to stress the importance of writing, social, and environmental responsibility throughout the class. Students were given instruction in disability etiquette and universal design. In addition, faculty brought the perspectives of their disciplines to the class. When individual faculty members disagreed about an approach, it was discussed and reasoned in front of the students.

The quality of the final projects in Studio 1 exceeded the expectations of the faculty. Students were unusually motivated by the desire to help children with disabilities and worked hard to ensure that the projects were suitable for the not-for-profit.

After seeing what students could do in Studio 1, we increased our expectations for Studio 2 and 3. Students performed at the higher levels of expectation.

Studio students definitely have more design experience than is typical at Rose-Hulman for freshmen. Studio students also have more hands-on practice. All students machined a top, made a fidget spinner, performed sheet metal operations, practiced breadboarding, and programmed Arduinos to perform desired tasks. In addition, students worked with real clients on authentic projects.

Conclusion

The goal of the studio is to give students an integrative experience that combines engineering topics, writing, professional responsibility while prototyping solutions to authentic problems or opportunities. We have been extraordinarily lucky to develop relationships with not-for-profits that allow us to accomplish these goals with our students. The quality of the work produced by our students has been encouraging. The major challenge for faculty is to scope the effort required in the studio so that students do not perceive they are grossly overworked and to support the transition from high school to college.

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