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Multi-Disciplinary Design: Implications for CS and Engineering Pedagogy

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Multi-Disciplinary Design: Implications for CS and Engineering Pedagogy

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Abstract: A new course offered at Brown University in fall 2021 entitled *The Robots Are Coming! The Robots Are Coming!* illustrates the power of multidisciplinary study and the beauty of collaboration among students. Co-taught by a CS/Engineering professor and a visiting artist-in-residence, the course brought together students from diverse majors from Brown University and the Rhode Island School of Design (RISD) and aimed to augment existing artistic robots and design new dynamic interactive creations. Students developed both technical and artistic skills while also contemplating and discussing as a class the uses of technology and its interaction within society. Some of the lessons learned from this unique course structure were the critical importance of communication and the educational value of learning from peers. Students stated that the course significantly enhanced and deepened their education more than any course strictly focused on their specific field of study. The unique curriculum design of the course lends itself to significant implications for the future of engineering and computer science pedagogy. Today's engineering education places a high value on becoming an "expert" in a given field; however, this course provides evidence that it may be equally worthwhile, if not more so, to invest time combining various fields of study to broaden and deepen students' overall understanding and to create a learning environment more conducive to success in the real world. It has been shown that a multi- and inter-disciplinary curriculum leads to greater performance within the classroom and beyond, encouraging a broader range of more diverse participants.

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Ashley Oelrich and Bridget Griswold were students enrolled in this course in Fall 2021. They continued to be involved in the design of the Think Bot robot during Spring 2022 and made significant contributions to the writing of this paper.

INTRODUCTION

The Robots Are Coming! The Robots Are Coming! was originally conceptualized by Dr. Iris Bahar, Brown University Professor Emerita in Engineering and Computer Science, and Eva Goetz, visual artist based in Portland, Maine [1]. For the prior year, the artist had been working with a technology team to build an installation of five different robots, which she called *Think A Bot It*. These robots were based on a dream the artist had: giant robots communicating to humanity via semaphore flag symbols and codes, asking humankind to wake up [2]. Eva Goetz's artwork is influenced by the landscape and narrative folk paintings of Texas and Mexico: bright and dusty colors with storytelling and patterns central to her work. The *Think A Bot It* installation was no exception to these themes. With her colorfully punctuated robots, the artist encouraged individuals to ponder the ways in which modern robotics and technology are impacting society and whether that impact was more beneficial or detrimental overall.

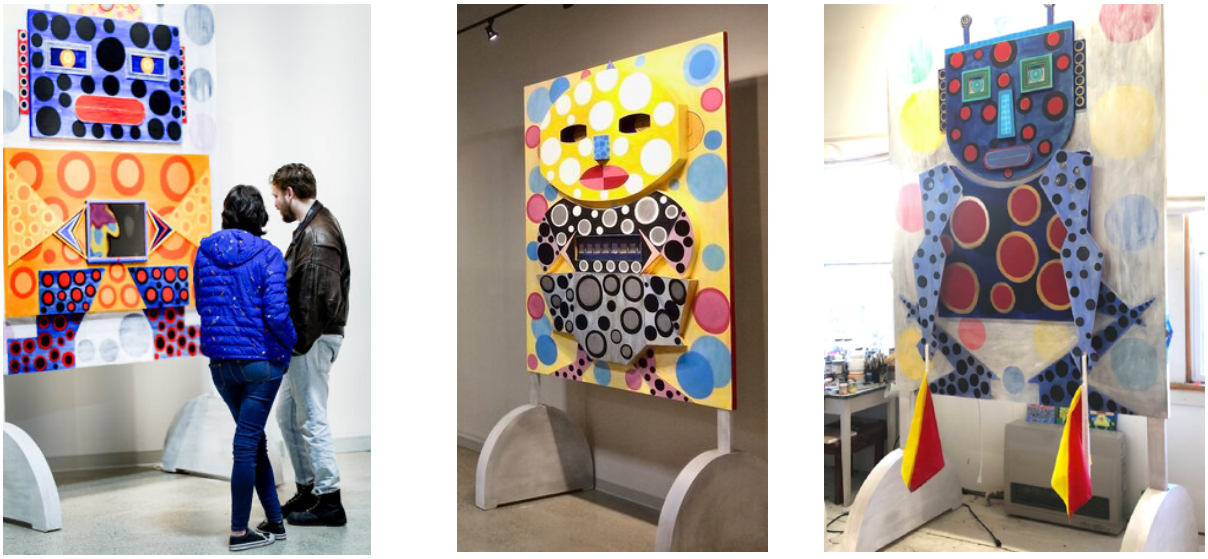

Figure 1: Eva Goetz's robots at an installation: (left) Morse Bot, (center) Think Bot, and (right) Flag Bot

The course was originally conceived by Dr. Iris Bahar as a means of fostering interdisciplinary collaboration and engaging students who are generally underrepresented in STEM fields. Her idea was to have students augment Ms. Goetz's robots from her *Think A Bot It* installation with new mechanical, electrical, software, and artistic features. Students would then design new dynamic and interactive creations of their own based on this experience with the artist's robots, all while considering the uses of technology and its interaction within society. To bring this course to life, the artist graciously donated all five robots from her *Think A Bot It* installation for student use and display to Brown University and co-taught the course with Prof. Bahar during the fall semester of 2021.

To broaden participation from diverse groups of students, Prof. Bahar removed almost all course pre-requisites normally found in engineering courses. This allowed a mix of sophomores to master's students at Brown University and Rhode Island School of Design (RISD) to enroll in

the course. It also attracted students from a broad range of majors (including engineering, computer science, social sciences, and visual arts) with more gender diversity typically seen in STEM (i.e., 60% of the class identified as female). The course was also designed to foster a deeply reflective environment among students regarding the current technological state of the world and its societal repercussions. There were 21 students enrolled in the class, which was held twice a week with the 2.5-hour class time split between lectures and hands-on student design of projects. Because the class was composed of students from various backgrounds from Brown and RISD, the Brown instructor's lectures primarily focused on ensuring a common level of understanding of the hardware and software components involved in each class project. This meant students from different disciplines established a foundation of knowledge essential for the successful completion of all projects. Artist Eva Goetz's lectures enhanced students' learning by shaping the way they viewed the technology they were learning how to create. She sought to increase awareness of the greater societal implications of modern robotics and encourage students to ponder the ethics of the technology they use every day. Additionally, she provided students with many examples of incorporating art with engineering and robotics to inspire them to not strictly focus on functionality in their projects, but equally to value their artistic message.

CURRICULUM DESIGN

The course work was split into three projects, each consisting of diverse teams working together to create a robot or robotic component. These projects were designed to build upon each other as student knowledge and expertise grew throughout the semester, while at the same time spark conversation and contemplation over the role of technology in society. The first two projects were focused on enhancing one of the robots donated by the artist. The robot, Think Bot, was originally designed to display messages with split flaps[1], but Eva and her team ran out of time and had to resort to an LED display instead (as shown in Figure 1, center). The intended result of the first two projects was for the class to have successfully replaced the existing LED display with an 8-character split flap display, cycling through poems written by the students, in reflection of the current technological environment. The first project focused on creating a single split flap.

The class was divided into five teams, each working towards the same final goal of a single functional split reel with 50 "flaps". The members of each team were assigned by the course instructors, in order to ensure all teams included students with a diverse range of skill sets: software, industrial design, electrical, mechanical CAD, etc. The student groups determined the necessary electrical and mechanical configuration on their own and were given the creative freedom to design unique housing for their split reel and software for controlling the motor. The open-ended nature of the initial project resulted in different designs and approaches, with varying degrees of functionality. Once completed, the teams presented their final split flap solution to the rest of the class, detailing their design choices and ways in which they approached problems. The class then had an open discussion to identify "best elements" from each group and determine a design for the full 8-character display that represented a mix of the best features from all 5 single split flap designs. The entire class worked together to complete this 8-character split flap display

[1] Split flaps are electromechanical display devices, once commonly used in airports and railway stations, to display the time of departures/arrivals.

Figure 2: Construction of the 8-character split-flap display: (left top and bottom) as a standalone structure, (center) preparing for insertion in Think Bot, and (right) completing the final electrical wiring.

as the second course project, again splitting up into 5 distinct teams; however, this time, each team was tasked with a different aspect of the split flap display: software, hardware/electrical, CAD, calligraphy and poetry creation, and documentation. All aspects of the display were student-designed, determined, and constructed — from housing, component selection, power delivery, software coding, and poetry composition. The poems reflected on the societal consequences of modern technology and robotics.

To ensure proper communication between teams, the documentation team was tasked with keeping track of progress and coordinating the various steps of the assembly process, making sure each team understood its role and completed it within a timely manner. Documentation representatives worked closely with each of the 4 other teams to track their progress and record their work in an *Instructables* site [3]. Nonetheless, students were still challenged with inter-team communication, a need for more clearly defined constraints and deliverable passed on to each team, and coordinating tasks across the different teams. Appropriately, many of these challenges reflect real-world scenarios in product design. However, despite the challenges, by the end of the semester, the new split flap display was mounted into Think Bot and the poems were successfully cycled through the robot, with 1-3 words being displayed at a time.

Think Bot set the stage for the remainder of the course. In working together, often through intense challenges, the 21 students bonded together. Students were humbled by the knowledge of their classmates and empowered by what they could teach each other. This built a collaborative and trusting class. Students wanted to work together and learn from their peers and were not afraid to bring in their own areas of expertise. The entire class was able to realize that it requires a team from very diverse backgrounds, in order to produce something with many complex components. This built a strong community in the class and allowed students to be less fearful entering into future projects in which they did not feel as if they possessed the entire set of skills needed for successful completion. It also had a humbling effect on some students' view that

their skills were the most critical to the project. Furthermore, students saw the importance of an artistic and multidisciplinary way of thinking and were more motivated to internally address the ways in which modern robotics and technology are impacting individuals and society.

STUDENT-CONCEIVED PROJECTS

Building off the motivations and learnings from the Think Bot split flap display, students were now ready to design their own robot creations. The final project selection began with pitches from each of the 21 students on an idea for a robot designed in the spirit of the artist's robots: one that challenged people to stop, think, and listen about our use of technology and its impact on society. Ultimately, students converged on 4 projects, based on pitches for 4 distinct ideas that inspired them the most. Student were free to choose which project to work on, but as a class, made sure all teams were comprised of students from diverse majors. As with the split-flap display, these projects were entirely designed and constructed by the students.

One of these projects was a hands-free page turner, designed to be used by handicapped individuals who otherwise could not flip the pages of a book they wished to read. The page turner represented the human-supporting potential of technology and brought people closer to the physical world by reading a book instead of a screen. The team used inverse kinematics to control the page-turner arm smoothly using positional targets. The aesthetic inspiration of their design came from an old-fashioned record player.

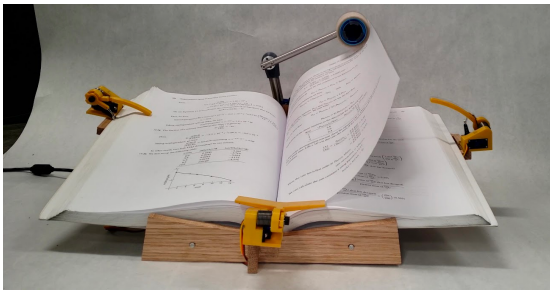

Figure 3: The Page Turner project

Another student-conceived project led to the design of a "dancing" scallop chest, which played along to the tune of *Blue Danube*. As the song played, the scallops moved up and down and opened and closed. The project was meant to raise awareness of human interference on natural habitats and environments impacting sea life. In nature, scallops open/close their mouths to swim away from danger. Students designed and fabricated the internal cam from scratch and synthesized the music by reading MIDI notes from program memory and converting them to sound waves output to a speaker.

Figure 4: The dancing scallop music box project.

The vending machine project (Figure 5, left) was inspired by the students' desire to build openness and connection at social gatherings. Features included a Venmo payment activated drink selection, a circular design symbolizing connection, and a printed message "receipt"

intended to spark reflective conversations at a social gathering with regard to current technology and its impact on them. Design features included multiprocessor communication, fine-tuned servo control, and acrylic and wood craftsmanship.

Finally, the "Light Bot" project was a cable driven robot that allowed audience participants to play with light and sound in a format meant to represent cohabitation of technology and humans in the world. The robot was design with a set of winches and cables that controlled an LED light source in space. With human hand motions, the human participants could indirectly control the location of the light course and create a song, while a long-exposure camera captured still photos of the experience.

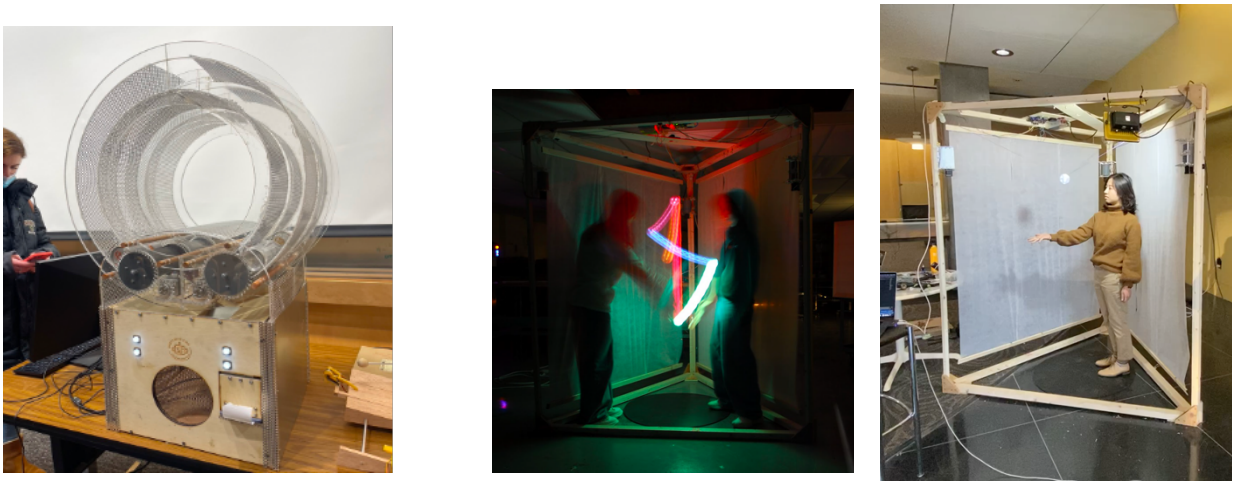

Figure 5: (left) The vending machine project and (center and right) the "light bot" project.

REFLECTIONS ON THE COURSE

Inherent to the success of the course was collaboration among students and between students and the two instructors. This was intentional, as collaboration is an integral part of any engineering, computer science, or design project in the real world. The instructors brought collaboration into every aspect of the course. Between the group projects and class-wide discussions, students from many different backgrounds were encouraged to interact with one another and to learn from and respect each other's unique expertise and skill sets. The success of the entire task was contingent upon all students completing their individual tasks in a timely manner and communicating their progress to the appropriate parties. In this way, the necessity of cross-group collaboration, while a challenge, was integral to the uniqueness and value of this course. The need for each team to understand the progress and decisions of the others forced students to learn from their peers, as well as teach. One student recalled: "As a computer scientist, I had to learn how to both listen and think from the mindset of an engineer, but also how to teach industrial designers how to think like a computer scientist." The ability for collaboration was due to the nature of the course itself: a diverse group of students who were motivated to make the world a better place. The students in the course were truly passionate about their studies, so they were excited to teach others.

Overall, students expressed great praise and satisfaction for *The Robots Are Coming! The Robots Are Coming!* course. Many said that it was hands down the most meaningful class they had ever taken throughout their studies at Brown. One student declared: "This was my favorite class I took at Brown, and it made me so grateful to be a student at this school. I felt so lucky to be around smart people who wanted to support and help me learn. I loved how passionate and enthusiastic my classmates were." The praise of the course was in large part due to the amount of collaboration it included. Many students felt the most impactful and unique quality aspect of the course was the way it so heavily emphasizes collaboration. One student said that while "at the beginning I felt stupid asking expert students questions about a subject I knew nothing about, I quickly realized how kind and willing to help my peers were. I was no longer scared, and we were constantly helping each other." When asked about the course, students recalled being so impressed with the skills and willingness to help their peers. Students were excited to learn new skills from their teammates and show their teammates what they already knew, so that they could acquire those skills as well. This was especially true between Brown and RISD students. As one student noted, "These are capabilities, now understood through collaboration with my classmates, that I will carry with me for the remainder of my life."

A key aspect of broadening participation in engineering is lower barriers to entry. This course enabled that by removing many pre-requisites, often relying on the students themselves to teach one other missing skills. The focus on artistic design, societal impacts of technology, teamwork and good communication skills inherently spoke to a broader audience allowing a more diverse group of students to participate and feel their voices were heard, welcomed, and valued. The interdisciplinary nature of this course also created opportunities to hear diverse viewpoints and experiences. It has also been found that taking an innovative, collaboration-focused, interdisciplinary approach to a computer science education can have lasting positive impacts on student outcomes, both in a university setting and in life beyond [4]. Additionally, it has been found that combining computer science with other fields of study under one major can significantly increase the number of students who want to pursue the degree, particularly in the case of women, which positively impacts the gender diversity within the field [5]. Moreover, the diverse makeup of the teams likely produced more creative and innovative solutions compare to teams composed of student with homogeneous backgrounds.

Finally, this course also addressed another issue found in much of engineering education. Specifically, much of STEM education focuses on a linear progression through curriculum. As a result, students must take a long list of pre-requisites before encountering any open-ended design courses. This effectively narrows participation in STEM as many students switch out of these STEM majors before getting to the "fun part". In addition, current design courses that are part of many STEM curricula tend to focus on prescribed projects with little or no open-ended component. This often leads to students' lack of motivation for learning a particular topic. In contrast, students expressed that taking this course significantly impacted their view on future courses they wished to take. As one student noted, "I never knew how much I loved robotics! As a computer science major, I knew that I was passionate about technology, but backended, with wires and machinery, [it] intimidated me. I now love and am driven to take any opportunity to create something with my own hands and will definitely continue to do this through my time at Brown."

LESSONS LEARNED AND PROPOSED IMPROVEMENTS

While this course is unique in many aspects given the donated artwork from Eva Goetz, if a similar course were to be offered again, there are a few modifications suggested to improvement outcomes and student experience. First off, coordinated teamwork is essential for successful completion of these projects. Teams could have been given better guidance on the importance of clearly and frequently communicating across teams, especially with regard to constraints, design assumptions and deliverables. Also, within teams, individual accountability needed to be better quantified throughout the project such that student performance could be more accurately assessed. Improving individual accountability may also ensure ideas from all team members are heard and considered. Finally, for a class-wide project such as the design of the 8-character split flap display, some flexibility in team assignments may be desirable, as students may need to be reassigned to different teams as the project progresses, to better address problems as they arise. These improvements may reflect policies that many successful companies have in place as they develop and implement their own projects.

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