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Robotics-empowered convergence engineering education

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Robotics Empowered Convergence Engineering Education

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Abstract: This paper presents the design and first-time offering of a convergence engineering course, "Introduction to Autonomous Robotic Systems," where students from four engineering majors worked in interdisciplinary teams to create submarine robots and accomplish complex autonomous missions. The technical knowledge covered in the course included: robot design, mechanical analysis, sensing and actuation, electrical system design, guidance, navigation, control, robot operating system, computer vision, object recognition, and mission planning. The students are engaged in a whole project cycle within one semester, such that they can experience how engineers with different backgrounds work together to solve real-world problems. The course plays multiple roles in the engineering curriculum, filling up the knowledge gaps left between majors, improving students' knowledge in and out of their majors, providing students with practical experience for internship or job interviews, and raising students' interest in engineering. Students' learning outcomes were assessed in three presentations, a demonstration, and a report. This course was designed and piloted at the College of Engineering, Computer Science, and Technology at California State University, Los Angeles. More than two in three students in the college are LatinX, and many are first-generation students. Many of these students may not have opportunities for practical engineering training without this course. In a survey conducted at the end of the course, students reported improvement in all of the following three areas: (1) knowledge and skills in and out of their majors, (2) self-efficacy in solving complex problems in diverse team settings, and (3) soft skills such as leadership, collaboration, and public speaking. Many students indicated the course offered very valuable real-world experience during their engineering education. Students also commented that this course experience is challenging but inspiring and motivating for them to pursue engineering careers. Their responses to open-ended questions revealed a high level of engagement and enthusiasm about the interdisciplinary team-based learning experience.

I. Introduction

Engineering education has been going through divergence and convergence at the same time. Divergence breaks a major into concentrations such that deeper learning experiences can be geared toward specific areas. Divergence help produces a highly skilled workforce with specializations. On the contrary, convergence emphasis on the deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks for addressing scientific and societal challenges and opportunities [1]. While we have experienced fantastic achievements in divergence, more and more specialized engineering disciplines are emerging, convergence is believed to be a new model that can stimulate new ideas and maybe produce new disciplines. Not only in education, but convergence can also lead to solutions to some grand challenges of today, such as protecting human health, solving climate change problems, exploring the universe, and maintaining sustainable development. Convergence plays an important role in stimulating innovation and discovery by merging ideas, knowledge, approaches, and technologies from diverse fields. Recognizing the importance of convergence, the U.S. National Science Foundation (NSF) has set up programs to foster convergence, encourage collaborations, and support creative thinking for solving complex problems in society. To differentiate convergence education from our existing models, Eigenbrode and Martin provide a visual description and comparison of disciplinary, multidisciplinary, interdisciplinary, and convergence [2]. They described convergence to have four characteristics, including cross-disciplinary and sectorial boundaries, having a common goal setting, developing integrated knowledge, and creating new paradigms. Here, convergence engineering education refers to a learning experience that integrates knowledge, methods, expertise, and experiences across disciplines and sectorial boundaries to solve a complex problem. This concept of convergence engineering education is derived from convergence research, a highly prioritized research type by the NSF [3]. Compelling problem-driven and deep cross-discipline integration are the two compiling characteristics of convergence research. Convergence engineering education is similar to interdisciplinary engineering education in that students cross disciplinary boundaries and develop integrated knowledge. Different from interdisciplinary engineering education, convergence engineering education emphasizes not only the growth of students' interdisciplinary knowledge and skills but also their development of self-efficacy and soft skills.

Robotics is an excellent tool for practice convergence education, and it is becoming a more and more popular tool for not only college but also k-12 for teaching Science, Technology, Engineering, and Math [4]. With its interdisciplinary nature, robotics integrates knowledge from almost all major engineering disciplines, including mechanical engineering for structural design and analysis, electrical engineering for designing power systems, sensors, and actuators, and computer science for programming. Moreover, almost all robotics-related activities require communication, collaboration, management, and innovation, which are fundamental skills in any work environment [5]. Additionally, robotics provides an excellent context for students to practice the engineering design process, apply their knowledge learned from the theoretical courses, develop technical skills, and improve their verbal and written communication skills [6].

Due to the limited time and units available during the four years of undergraduate education, most of the current engineering curriculum doesn't have many opportunities for students from different disciplines to work together in a convergence education setting [7]. Convergence education experience is only available from some extracurricular activities, such as robotics competitions. Since many students start to have part-time jobs off campus, only a limited number of students have access to those opportunities. For students from a university like California State University, Los Angeles, the situation may be worse since many students have part-time jobs that are not related to their major. Having this course in the curriculum provides opportunities for working students to obtain career-related experience, which will be beneficial for their future employment. Moreover, many students have been taking classes online due to Covid, which makes this course particularly important to bring students together and back to campus to practice engineering and develop professional skills. Hence, this course aims to bridge the gap between the underserved students and others we have witnessed in our current engineering curricular settings.

The paper presents our recent development and experience in robotics-empowered convergence engineering education at California State University, Los Angeles, a Hispanic minority-serving institution whose engineering college has one of the largest enrollments of LatinX students in the country, with more than two-thirds of undergraduate engineering students LatinX and most of them the first generation in college. This education practice is offered through a new robotics course, "Introduction to autonomous robotic systems." The development of this course was initially motivated by limited opportunities to engage in hands-on projects resulting in a lack of preparation to work on complex robotic competitions. With funding from the Office of Naval Research, the course was designed as a convergence engineering learning experience for students from all major engineering disciplines. The course ultimately enrolled students from all disciplines of the College of Engineering, Computer Science, and Technology (ECST), and not just those whose trajectory was likely to include building robots. It provides students with two critically important experiences: the opportunity to design and build something and the opportunity to work across disciplines. Here, students work in diverse groups to address one complex problem of creating a submarine robot for an autonomous mission. The course has an enrollment of 24 students, who are mainly from three majors – mechanical engineering, electrical engineering, and computer science. They are divided into five teams working toward a mission of each team's choice. The candidate missions include a treasure hunt, an Atlantis adventure, disarming a mine, and feeding fish. The technical knowledge covered in the course consists of robot design, mechanical analysis, sensing and actuation, electrical system design, guidance, navigation, control, robot operating system, computer vision, object recognition, and mission planning. Students work with their teammates to determine how to discompose the mission into smaller pieces and further into design components on the robots under the instructor's guidance. Students are assessed through three presentations, a demonstration, and a report. A survey is conducted to assess the impact of this convergence learning experience on the following three categories (1) knowledge and skills in and out of students' majors, (2) self-efficacy in solving complex problems in diverse team settings, (3) soft skills such as leadership, collaboration, public speaking. Improvements were observed in all three categories. Students also mentioned that this course adds valuable experience to their job interviews.

The rest of the paper is organized as follows. In section 2, the development of the convergence course is explained. In section 3, the survey results and the analysis are provided. Conclusions are drawn in section 4.

II. Course Experience

2.1 Course design

A typical engineering program is generally divided into Civil Engineering, Mechanical Engineering, Electrical Engineering, and Computer Science. In this model, students choose and stay within one major to complete their four years of undergraduate education. The practice offered in each major is mostly specially tailored toward the major. Most of the time, the problems are abstracted or simplified so that students can use the knowledge learned from their discipline to solve them. We noticed significant gaps between disciplines as we pulled students from multiple disciplines to work on an international robotics competition. The competition requires students to solve more complex problems, but a lot of knowledge essential for effective communication between engineers from different disciplines is missing. Many students misunderstand how other fields work and what students from other disciplines expect them to do.

The course has a common theme of developing a submarine robot to complete a series of tasks autonomously. To complete the task, students will need to brainstorm the design of the robot, including the mechanical, electrical, and software components, and then build and test the robots. They are encouraged to communicate in making decisions as a team. Students have chances to learn how to work in a team with diverse disciplines. Through this design, we will discover how this convergence course design will improve students' understanding of knowledge of their own and other fields, confidence in engineering, engineering skills, and readiness for jobs.

This course is offered as an upper-division technical elective to all undergraduate and graduate students. This course is composed of both a lecture and a lab component. The lab portion of this course heavily emphasizes group work, allowing students to apply the theories they learned in the lecture portion of the course to a practical application while honing their communication, problem-solving, and teamwork abilities. Two mechanical engineering majors, two electrical engineering majors, and two computer science majors were recruited by each student who volunteered to be a team leader during the first week of the course. It was important that these team leaders demonstrated a good work ethic and provided clarity to their team when it came to meeting certain deadlines within the class. During the lab portion of the course, students were engaged in tasks such as assembling the robot's mechanical chassis and electronics hull, soldering components onto a custom PCB, mounting electrical components onto an electronics shelf, and programming. Moreover, it was expected that students would spend time outside of class working on the activities that most likely weren't finished in the lab. Two teaching assistants were responsible for maintaining a close watch on each team's progress inside and outside of class, ensuring that they understood what needed to be done, and assisting students with any questions or needs they might have. Furthermore, the teaching assistants were in charge of tracking the class's inventory to ensure that the students had all the parts necessary to complete the project.

2.2 Content breakdown

The submarine robot we developed for this course as well as its exploded view is shown in Figure 1. We can see the Computer Aided Design (CAD) model is almost identical to the real robot when built. The main content in the course includes mechanical design and analysis, electrical design and analysis, software design and development, sensors and actuators, embedded systems, computer vision and artificial intelligence, guidance, navigation and control system, and mission planning.

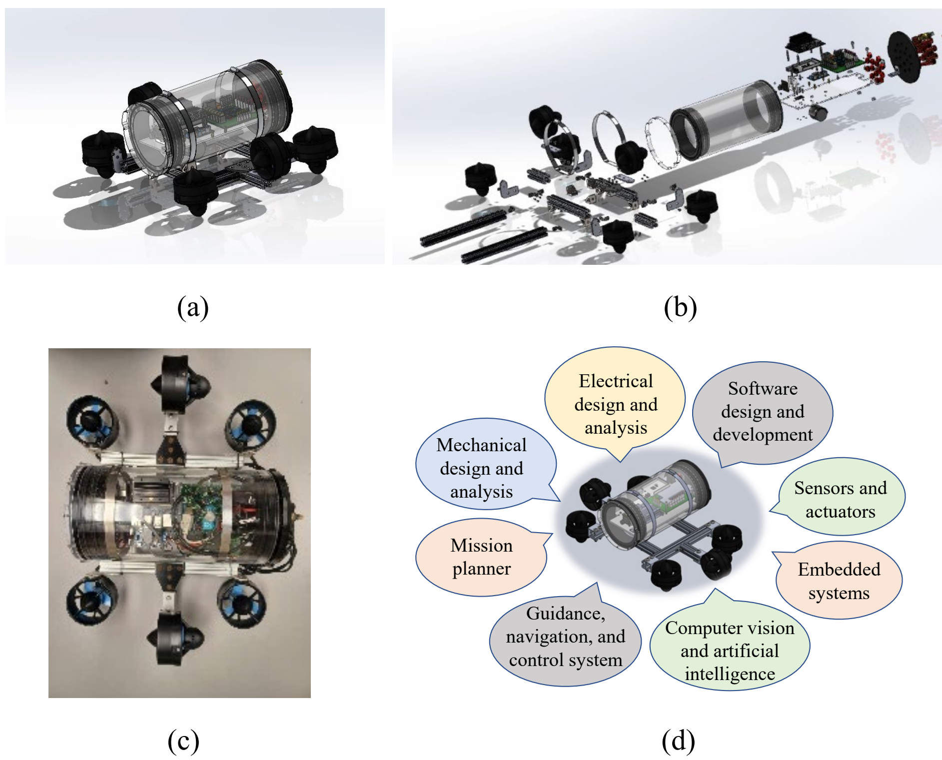

Figure 1. The robot developed for this course (a) CAD model, (b) exploded view, (c) robot, (d) knowledge content

The technical course learning objectives spread among all major engineering disciplines. Upon completion of this course, students will be able to

- describe the fundamental architecture and development process of robotic systems, artificial intelligence with applications in robotic systems, and practical considerations in designing submarine robotic systems.
- explain the principles of commonly used sensors and select proper sensors according to requirement.
- explain the functionalities of guidance, navigation, and control system.
- program microcontrollers to read sensors and control actuators.
- program Jetson Nano motherboard for a simple robotic software system using Python

- implement a guidance, navigation, and control system.
- implement a machine learning algorithm for object recognition.
- implement a finite state machine for mission planning.

The technical content of the course is broken down into mainly three interconnected components, including mechanical, electrical, and software components. The mechanical portion of the class has a strong focus on using SolidWorks to analyze an accurate 3D model of the robot. Stress analysis will be done in SolidWorks to identify the critical components of the robot and find the safety margin. Students will then propose solutions for improvements to the robot design if it is needed. Ansys will be used to conduct a thermal analysis of the robot. The effectiveness of the robot's cooling system will be inspected by looking at the temperature change over time, and students will determine if the robot can operate in its environment. The main mechanical concept is for students to identify problems and propose solutions.

The electrical portion of the class has a strong focus on the power system, the perception and actuation of the robot, and the guidance, navigation, and control (GNC) system. Students learn the power system of the robot, which is composed of a battery and converters. The terminologies used to describe, classify, and compare batteries are also explained. This includes the understanding of cells, modules, packs, battery classifications, and C-rates. The working principle and typical application of converters are analyzed, including DC boost converters, voltage regulators, and in our case, buck converters. Along with the power system, PCB design software will be used to inspect the robot's custom ESC board, and circuit analysis will be done with the power draw of all the components. Students will be taught to program microcontrollers to collect data from the robot's many sensors, including an inertial measurement unit, barometer, and temperature sensor. The different types of DC motors are taught, with an emphasis on our robot's brushless three-phase motors within the thrusters. The robot's GNC system is then analyzed, where students will learn PID control theory, perform PID tuning on their robots for motion control, and learn the basics of trajectory planning.

The software portion of the class strongly focuses on understanding the software architecture, including the libraries, machine learning algorithms, and finite state machine used. Students learn the basics of layered system architecture, including the driver, platform, algorithm, and user interface layers. They then inspect the robot's software design to understand which features belong to which layer. Students will also learn the basics of the Robot Operating System (ROS), which is the software framework used for their robots. The network of elements consisting of nodes, topics, and services is analyzed, and custom data packets are implemented. Following this, the machine learning algorithms used in computer vision for object recognition will be introduced, which includes the basics of OpenCV, and a model for a custom object trained with YOLOv4 and Darknet. Students will also learn how to use the Jetson Nano motherboard to program in Python and implement a finite state machine for the robot to conduct a mission. An example state machine is used to show the basics of mission planning, where the robot will dive underwater, search for a custom object, bump into an object, and return to the starting position. After integrating all the software components together, students create a testing plan and procedure to optimize their robot's performance.

III. Survey and analysis

A survey was conducted on the last day of class, with all 24 enrolled students responding. Earlier in the semester, the two teaching assistants and another two students were interviewed. The survey and interviews were designed to document (a) the impact the course had on students' confidence in their own technical, communication, and other soft skills that the industry requires and (b) to learn what students experienced when they were challenged to work with peers from other engineering disciplines to design and develop a product. The survey included several open-ended questions that, along with the interviews, allow us to add to this paper the students' course experience as described in their own voices.

The demographics of students in this course are shown in Figure 2. It reflects the diversity of the college of ECST. 13 of 24 students responding to a question about ethnicity were LatinX. A majority of respondents (15) indicated an expected graduation date of 2023, meaning that they enrolled in the Robotics course during their second- or third-to last semester at college. More than half of the students (55%) were community college transfer students.

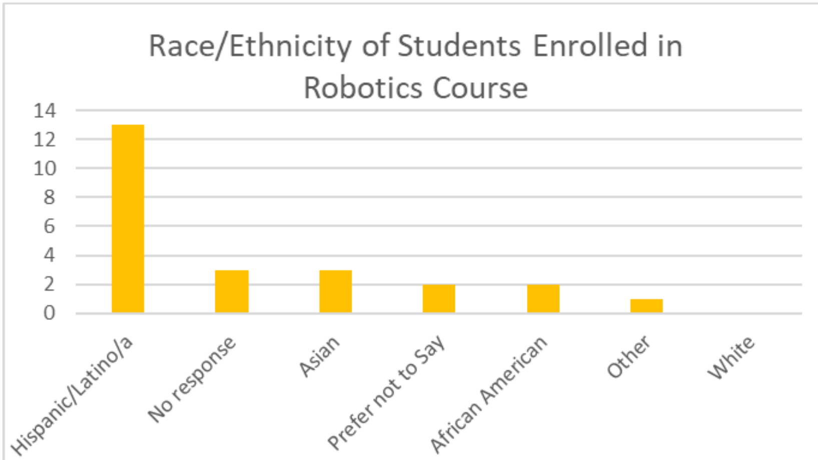

Figure 2. Student participants by race/ethnicity

To understand the impact of the course, information on students' previous experience with hands-on engineering projects in their major was also collected, as shown in Figure 3. Only 8 students (33%) had taken courses in the past that provided hands-on experience in their major. Another 8 students had obtained hands-on experience in their major in engineering clubs (3), internships (2), jobs (2) or working on a personal project (1). Seven students, all about to graduate, had no prior experience with hands-on engineering projects in their major.

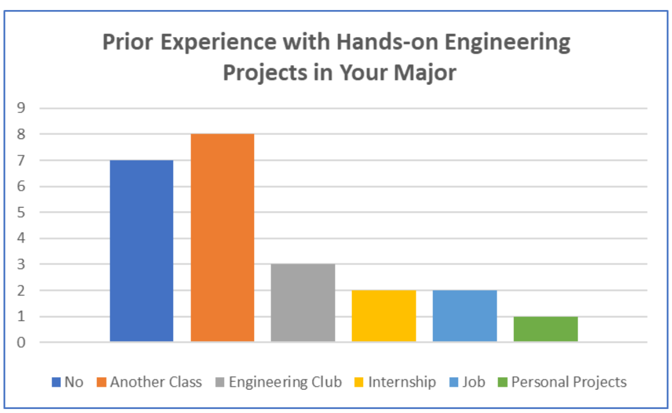

Figure 3. Participants' previous hands-on projects in their major

Students were asked to assess their skills and confidence at the beginning and end of class in two major areas: technical/engineering skills and soft skills. Here, the engineering/technical skills include (i) fundamental knowledge and skills required across engineering, (ii) understanding of your own engineering discipline, (iii) understanding of other engineering disciplines, (iv) hands-on and practical engineering skills, (v) knowledge of how a robotic system works, (vi) knowledge of programming an autonomous robotic system, and (vii) knowledge of power distribution and building a circuit board. And the soft skills consist of (i) the ability to work effectively in a team, (ii) the ability to lead a project involving engineers from multiple disciplines, (iii) public speaking, (iv) the ability to think creatively/outside the box, (v) ability to communicate ideas to (future) engineers from your own discipline, and (vi) ability to communicate ideas to (future) engineers from outside your discipline. The results are shown in Figure 4 and Figure 5. At the starting point, a large majority of students indicated they had no or very limited skills in three technical areas, including knowledge of (i) how a robotic system works; (ii) how to program an autonomous robotic system; and (iii) how to design and build a power distribution circuit board. Students also gave themselves very low ratings in their assessment of their understanding of other engineering disciplines and their hands-on and practical engineering skills. The areas where students expressed the greatest confidence at the outset of the course were their ability to work effectively in a team and, related, their ability to communicate ideas to future engineers from their own and other disciplines. When assessing their skill levels and confidence at the end of the course after they completed the survey, the highest average rating was still in the ability to work effectively in a team, but two new areas rose to the top: the ability to lead a project involving engineers from multiple disciplines and hands-on and practical engineering skills – an area that saw one of the lowest average ratings at the beginning of the course. Most noticeably, students' confidence in both engineering/technical and soft skills is significantly improved in all areas.

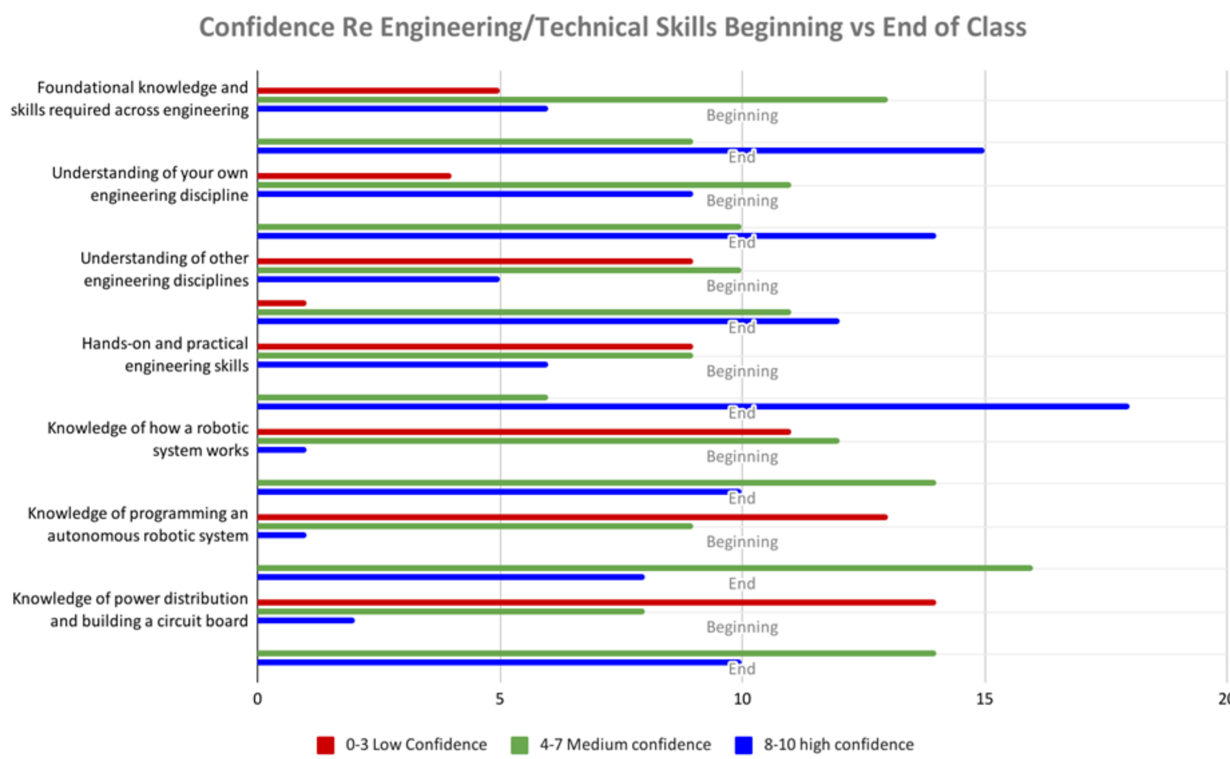

Figure 4. Changes in students' confidence regarding their engineering/technical skills

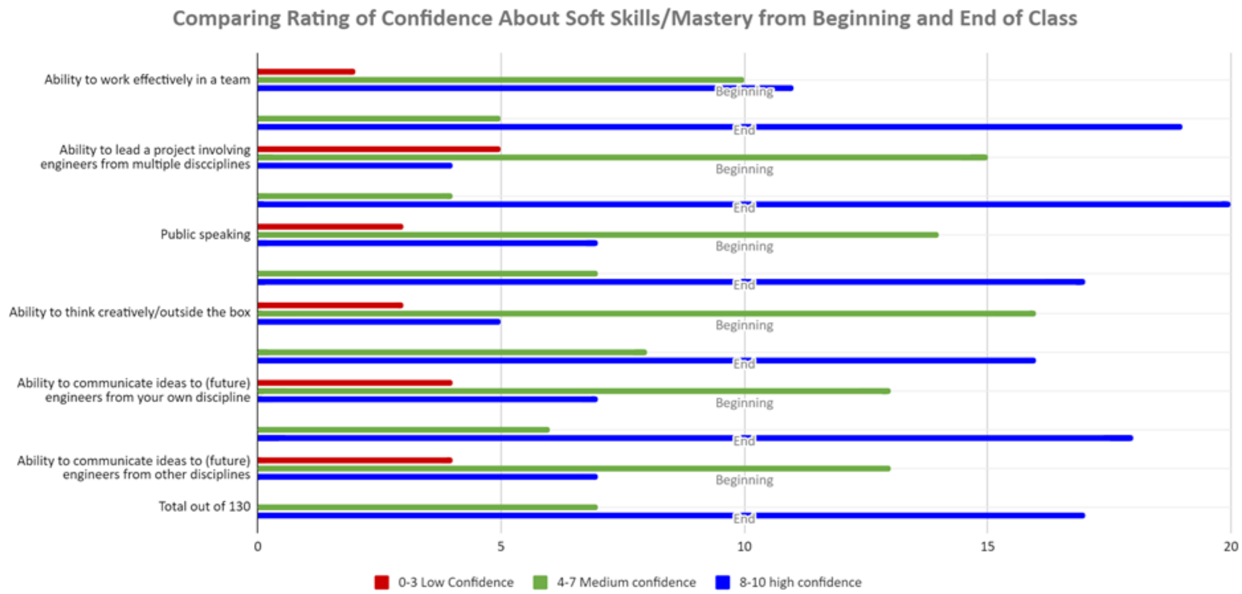

Figure 5. Changes in students' confidence in soft skills

The increase in confidence and skills they experienced from the beginning to the end of the course is summarized in Figure 6. The greatest increase in knowledge and skills were in the three technical areas that students initially rated as their weakest: knowledge of programming an autonomous robotics system, knowledge of power distribution and how to build a circuit board, and knowledge of how robotic systems work. Students experienced a more than 100% increase in each of these skill areas. With the prerequisite requirement for the course limited to completion of only one programming course, there was a lot of room to grow. However, the increase in confidence and skills students experienced, especially related to their knowledge of programming an autonomous robotic system, was over 160%. Two other areas that speak to the project's ultimate goal of developing students' readiness to work on real engineering projects across disciplines also saw spikes in student skills and confidence: students' hands-on and practical engineering skills and their ability to lead a multidisciplinary engineering project. Both areas saw increases of more than 60% in terms of students' assessment of their own skills and readiness.

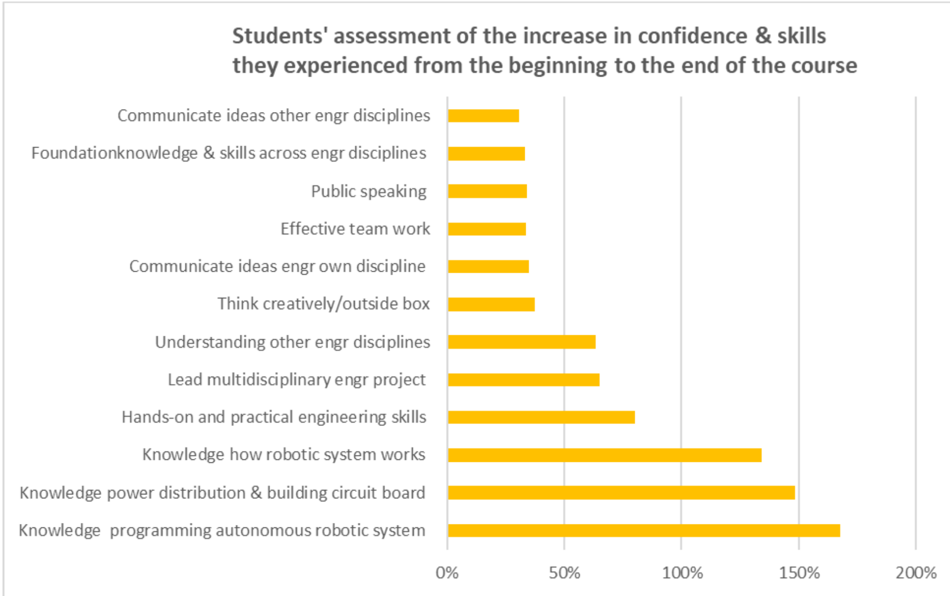

Figure 6. Students' increase in confidence and skills from the beginning to the end of the course

Table 1 depicts the impact that students felt the course experience had on their readiness to find the right kind of job openings, feeling confident that they have something to offer and successfully convey what they are able to do in a job application and, especially, in a job interview. More than 70% of students indicated they believe the course experience had a "very high" impact on their readiness in all these areas. The remaining students felt the course had "some" impact.

Table 1. Impact of the course on students' readiness for employment

Students' assessment of the impact of taking the Robotics course on internship/job applications	Develop a strong job application/ portfolio	Ability to convey in a job interview what I'm able to do as an engineer	Knowing what kind of job openings are right for me	Feeling confident that I have something to offer
Very High	17 (74%)	18 (82%)	16 (73%)	17 (77%)
Some	6 (26%)	4 (18%)	6 (27%)	5 (23%)
Total	23 (100%)	22 (100%)	22 (100%)	22 (100%)

In an open-ended question, students were asked which skills and competencies they wanted to develop more as a result of their experience in the course. Among 21 responses, more than 70% of students indicated they want to learn more about programming and coding. I would like to develop the software skills required to further program robotic machines, an ME major stated. An EE commented: "I want to learn more about the control system side of the robotics code." Students were asked what they learned from and considered challenging when working with peers from other disciplines. The students' responses – and observations from the TA interviews – underscore how engaged students were in their projects with most students who were able to stay continuing to work long after the class was over, not just once, but routinely. Through the interdisciplinary experience, students met and collaborated with peers from disciplines they knew little about, often realizing that it would be useful to build additional knowledge and experience outside of their own major. In some cases, the time pressure meant that students who were, for example, computer engineering majors would work on programming while their peers from other majors mostly observed. However, several students observed in the survey that their project experience had enjoyed opportunities to obtain hands-on practice in areas outside of their major. As one female mechanical engineering student observed: “Electrical engineering can be fun and not scary.” An electrical engineering major commented: “I learned what other engineering disciplines learned, such as stress analysis of an object and how it is implemented on solid works.” Other students highlighted the teamwork and the pride they felt about the way their team members built something together that incorporated the different skills each major brought to the table: “Although we have different disciplines, we all got along well. With good communication, even if not everyone knows how to do every aspect of a project, it can still get completed well by people putting different skillsets together. Students also commented as follows. “This was my favorite course in my entire educational journey, it was challenging and a lot of work, but extremely interesting. Figuring out how to build the robot and how to manage any issues that we ran into is one of the reasons I aspired to be an engineer.” “This course offered a lot of “real world” experience that I feel a lot of other course don’t offer. Being able to meet and work with people from other majors and seeing how our skillsets combine to form one project really motivated me to work harder in my own field since I saw the result of my education so far.”

In describing challenges they encountered, a number of students explained they and their teammates had struggled at times to communicate across disciplines. “[we were] unable to communicate about the topic due to lack of information of specific terms” Another student expressed a similar challenge: “A challenge I faced was not knowing what their topic was and how to solve for their calculations.” Students were asked to identify opportunities to improve the course experience. They pointed to delays in getting the right materials and difficulties experienced because some of the initial phases of building the robots required more time than the course design anticipated. Most importantly, there was an assumption that students would know how to solder because this skill is addressed in an introductory engineering course at the College of ECST. However, more than half of the students were transfer students who had not taken the introductory course. Delays meant that, in some cases, there was limited time for students to share knowledge across disciplines and teach each other new skills. For example, toward the end of the course, when the main task was programming the robots, the computer engineering students were so pressed for time that they had limited opportunities to engage teammates from other disciplines in the different steps of the process. This meant that the students from other majors had limited opportunities to learn what the computer engineering students were doing, while the computer engineering students did not enjoy the full opportunity to explain what they were doing to their teammates.

Finally, one of the more important messages conveyed in the survey and interviews was that students ought to have more opportunities throughout their undergraduate engineering experience to engage in the kind of hands-on, interdisciplinary learning that the Robotics course offered. The course is an elective, meaning that, at this time, only a small percentage of the engineering students at the College of ECST will have the opportunity to benefit from the course experience. The course designers – and, it appears, students who enrolled in the course – believe that all engineering students would benefit from opportunities to learn with and from each other by collaborating on hands-on, interdisciplinary projects whether these are embedded in other courses or offered as stand-alone courses.

IV. Conclusion

Motivated by bridging the gaps between disciplines in undergraduate engineering education, we designed this robotics course and offered it as a convergence engineering education experience. Students from multiple engineering disciplines were brought together to take the course to prepare students ready for jobs. A survey has been conducted, and the results show that students' engineering skills and confidence were improved in all categories of this study. Students experienced a more than 100% increase in knowledge of programming an autonomous robotics system, knowledge of power distribution and how to build a circuit board, and knowledge of how robotic systems work. They also experienced a more than 30% increase in all soft skills, including communicating ideas within and outside their own discipline, public speaking, effective teamwork, and thinking creatively/outside the box. Challenges faced by the course are in that (i) students do not have enough pre-knowledge to communicate appropriately, (ii) preparation of materials/components and tools ready for the whole class, and (iii) limited time for the course being offered as regular 3-unit course and the time left for programming is limited. Since this is the first time the new course is offered, valuable experience has been passed to the instructors who will teach the course in the future.

V. Acknowledgement

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Reference

[1] D. J. C. Herr *et al.*, "Convergence education—an international perspective," *J. Nanoparticle Res.*, vol. 21, no. 11, 2019, doi: 10.1007/s11051-019-4638-7.

[2] L. Wright, S. D. Eigenbrode, and T. A. Martin, "Architectures of adaptive integration in large collaborative projects," vol. 20, no. 4, 2015.

[3] B. Akbar, J. Brummet, S. Flores, A. Gordon, B. Gray, and J. Murday, "Global perspectives in convergence education," *J. Nanoparticle Res.*, vol. 21, p. 229, 2019.

[4] S. Anwar, N. A. Bascou, M. Menekse, and A. Kardgar, "A systematic review of studies on educational robotics," *J. Pre-College Eng. Educ. Res.*, vol. 9, no. 2, pp. 19–42, 2019, doi: 10.7771/2157-9288.1223.

[5] I. M. Verner, D. Cuperman, and M. Reitman, "Exploring robot connectivity and collaborative sensing in a high-school enrichment program," *Robotics*, vol. 10, no. 1, pp. 1–19, 2021, doi: 10.3390/robotics10010013.

[6] M. Pozzi, D. Prattichizzo, and M. Malvezzi, "Accessible educational resources for teaching and learning robotics," *Robotics*, vol. 10, no. 1, pp. 1–21, 2021, doi: 10.3390/ROBOTICS10010038.

[7] A. K. Noor, "Envisioning engineering education and practice in the coming intelligence convergence era - A complex adaptive systems approach," *Cent. Eur. J. Eng.*, vol. 3, no. 4, pp. 606–619, 2013, doi: 10.2478/s13531-013-0122-9.