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Work in Progress: Entrepreneurship and Senior Design Program Collaboration Towards Multidisciplinary Design

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Dr. Rachana A Gupta is currently a Teaching Professor and Director of the ECE Senior Design Program. She teaches and mentors several senior design students on industry-sponsored projects (On average 25 / semester) to complete an end product. These projects include all aspects of System Engineering: concept design, product design and design trade-offs, prototyping, and testing (circuit design, PCB, mechanical fabrication, algorithm development). These projects have included Robotics Platforms, Planning, Monitoring and Control algorithms, Sensor Interface, User Interfaces, Wireless communication, Signal Processing, etc. All of this involves direction and teaching teams to use the required tools and apply engineering skills to transform a concept into a product. She also manages interdisciplinary senior design projects in collaboration with other engineering departments such as Textiles Engineering, mechanical engineering, etc. Beyond senior design, she has also created and teaches undergraduate and graduate-level classes in ECE (Python in Engineering, Practical Engineering Prototyping (PrEP). She also has designed and taught ECE Robotics summer camp (2012-2017). Dr. Gupta earned her Bachelor of Engineering in Electronics and Telecommunication Engineering from the University of Pune, India, and received her MS and Ph.D. in Electrical and Computer Engineering from North Carolina State University (2010). Her Ph.D. was to design computer vision algorithms for autonomous navigation for cars. She started her own engineering consulting company in 2010, working on product development projects such as an automated air suspension system for vehicles, an active suspension system for heavy-duty off-road vehicles (currently DARPA funded), a vision tracking system for race cars tracks, etc. She joined NCState as Assistant Teaching Professor in 2012. Dr. Gupta's current research projects focus on sensor systems and engineering design education.

Dr. Gupta likes to tinker with new technology and work on small hobby projects in her basement lab. Her other hobbies include reading, classical dancing, and traveling.

Mr. Marshall Brain, North Carolina State University at Raleigh

Marshall Brain is most widely known as the founder of HowStuffWorks.com, an award-winning website that offers clear, objective and easy-to-understand explanations of how the world around us actually works. The site, which he created as a hobby and took through several rounds of venture funding totaling approximately $8 million, was purchased for $250 million by Discovery Communications in 2007.

As a well-known public speaker with the ability to deliver complex material in a way that is easily understood by audiences of all types, Brain is a regular guest on radio and TV programs nationwide. He has been featured on everything from CNN and Good Morning America to The Oprah Winfrey Show. In 2008 and 2009, he was the host of the National Geographic channel's Factory Floor With Marshall Brain, a series of one-hour factory tours taking the viewer on a journey into the world of product design, engineering and manufacturing.

Brain is the author of more than a dozen books, including "The Engineering Book" from Sterling Press, as well as a number of widely known web publications including How to Make a Million Dollars, Robotic Nation and Manna. His book The Teenager's Guide to the Real World is now in its tenth printing and was selected for the New York Public Library's prestigious "Books for the Teen Age" list. He frequently works with students at all levels to help them understand science and technology topics, entrepreneurship and how the world works.

Today Marshall Brain is the director of the Engineering Entrepreneurs Program at North Carolina State University, and lives with his wife and four children in Cary, NC.

Work in Progress-Entrepreneurship and Senior Design Program Collaboration towards Multidisciplinary Design

Abstract

Creating collaborative design projects between the Engineering Entrepreneurs Program (EEP) and the Electrical & Computer Engineering Department's Senior Design (ECE SD) program didn't only add value to both programs but also proved to be a key aspect in building a foundation for true multi-disciplinary senior design at North Carolina State University (NC State). The EEP supports multi-disciplinary teams where seniors from several engineering departments form a team and suggest a solution to an existing real-life problem. They also devise a viable business around it based on the market and implement the first basic prototype. On the other hand, in the ECE SD program, a team of ECE engineers is given a problem by an outside entity called *the Sponsor* (industry, academia, company, individual, etc.). The sponsored team then produces a viable product design solution to the problem, builds multiple product prototypes, tests, and verifies them based on the product requirements. While the EEP program focuses mainly on market exploration, customer study, and business planning, the ECE SD program's direction is towards system engineering, product design exploration, prototype building, verification, and in some cases, manufacturability. Therefore, the authors saw a clear opportunity to collaborate and broaden the horizons of both programs and deserving teams on both sides. This collaboration enabled creating a model and platform for multi-disciplinary engagement from students and faculty in engineering capstone design. The authors implemented this collaboration model with a pilot project three years ago. This model was slightly modified based on the lessons learned and learning outcomes reported by the participating EEP and ECE SD teams. This model brought forth some keen observations and lessons, which the authors have seen as the first step in forming a comprehensive multi-disciplinary design program. The preliminary impact of these steps is that 15 to 20% of the ECE SD program's design projects are multi-disciplinary (with 6 to 8 faculty members from several departments as mentors) and are growing. This growing multi-disciplinary collaboration has also brought in additional annual funding. This paper shares the structure, phases, advantages, outcomes, and impact of this collaboration model, which can be amended to collaborations between other programs. The paper also describes successes, failures, and learning lessons from this multi-disciplinary collaboration model and closes with the next steps.

Introduction

The value of teaching innovation [3],[18], entrepreneurship mindset [2],[12], and multi-disciplinary teamwork [6] has been recognized and put into practice at various universities using several different models [11],[18]. There have been many ideas to train students to innovate and demonstrate good multi-disciplinary teamwork [2],[3],[6],[8]. But at the same time, several challenges in establishing true multi-disciplinary design programs and teams have been reported in the literature [8],[16],[14]. These include different operating methods, lack of knowledge

about other disciplines, steep learning curve [8],[14], and many more. And even then, simply forming multi-disciplinary design programs or adding entrepreneurial teaching is not enough. Strategies to assess the impact of such programs and collaborations are the key to continuous improvement [10],[13].

Authors have noticed in general two types of programs across the board; the ones that teach entrepreneurship mindset and engineering innovation as part of engineering education [9],[12], and the others that focus on core multi-disciplinary engineering design [5],[17], each with their unique learning outcomes and skill development. In general, between Engineering Entrepreneurship (innovation, market, customer study, and business planning) and Engineering Design (design exploration, system engineering, product implementation), most students tend to have a stronger natural inclination towards one than the other. In real life, though, people with an entrepreneurship mindset and people with technical design skills working well together with a good overlap is crucial to success. There have been some successful attempts to add lessons, companion courses, or integrate entrepreneurship [4],[7],[11], add commercialization as part of senior design [15]. There have also been a few collaborations where students from business schools and engineering departments form multi-disciplinary teams [16]. Such team merges and lesson/course additions help students to understand the bridge between the two mindsets. In this work in progress, a unique model is developed to semi-merge the entrepreneurship program and senior design program teams to give both a valuable real-life experience to navigate and manage the bridge successfully.

At NC State, students in their senior year can opt for either Engineering Entrepreneurship Program (EEP) or Senior Design program in their respective departments to fulfill their senior year capstone requirements. Overviews of EEP and Senior Design in Electrical and Computer Engineering Department (ECE SD) are as follows.

Overview of EEP

The EEP is part of the broader Entrepreneurship Initiative at NC State and is open for all engineering students. It comprises a two-semester sequence (offered Fall-Spring) where students learn about launching new technology products/services, start-up companies, and designing and building new products. The broader goal is to develop an entrepreneurial mindset in students. Students form teams themselves, choose an idea together, prove a market for their idea, prototype the idea, and build a viable business plan and financial model. At the end of the process, the teams own the core concept and intellectual property for a valuable start-up company to take with them after they graduate. The core deliverables for EEP students are (i) Product Development Plan, (ii) Business plan, (iii) Financial model, (iv) Prototypes 1 and 2, (v) Project status reviews (v) Senior design day public presentation, (vii) Final investor presentation, and (viii) Technical documentation. Recommended textbooks are “Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers” [19] and “The Startup Owner’s Manual: The Step-By-Step Guide for Building a Great Company” [20].

Overview ECE SD

The ECE SD program is a traditional capstone design program in the Electrical and Computer Engineering department. It is a two-semester class sequence (offered as both Fall-Spring and Spring-Fall cycles). Students learn product development, system engineering, design explorations, prototyping products, test, and verification and introduction to manufacturability. This program's broader goal is to teach various aspects of the product development process stated above and beyond, such as project management, team building, and design presentations. In this class, external entities (multiple companies, non-profit organizations, state and federal agencies, individuals, research labs and centers, students) submit/sponsor projects. Instructors form teams, teach and guide students about building a product prototype from a concept by following the product development process. The core deliverables for these classes are (i) Product Requirements and market summary (ii) Technical Design Reviews (Preliminary in the first and Critical in the second semester), (iii) Project Plan (iv) Technical Prototype demos (total seven/eight spread throughout the two semesters) (v) test and verification plan, (vi) Detailed Design Documents (vii) Project Status reviews (viii) Final Senior Design Day public presentations (two) (iv) Final Design Document package and product prototype delivery to the client. Classes also include several guest lectures from the industry on project management, project presentations to the clients, basics of general prototyping, etc.

Fundamental reasoning behind the collaboration

At the end of their first semester (fall), the projected status of the EEP teams is to have solidified the project idea, have a preliminary business plan and financial model with customer and market study support. At this stage, these teams have also identified the essential technical skills needed to implement a proof-of-concept prototype for their project idea. Such a prototype will help with the final business planning as well as an investor presentation. We observed that this made several well-performing EEP teams suitable to be "a sponsor" for the ECE SD class beginning in the following spring. Several EEP teams also identified a need for support from a core Electrical and Computer Engineering team to build a successful prototype for their project idea. Since EEP teams use their second semester (spring) for designing and prototyping, these teams often have enough time to create very preliminary prototypes for their projects.

On the other hand, after the product requirements are set at the beginning of ECE SD's first semester (spring), ECE SD teams spent most of their time in several cycles of designing, prototyping, testing, and project planning through spring and next fall. Therefore, ECE SD teams' proof-of-concept product prototypes are much further along and much closer to a final product by the end of ECE SD's second semester (next fall). Such prototypes could be extremely valuable for EEP teams to apply for serious business funding after their graduation. The EEP and ECE SD team status and team skills during the various semester were identified as ripe and conducive to a successful collaboration to form multi-departmental teams. The partnership cycle is three semesters long. ***Table 1*** and ***Table 2*** explain both teams' stages in their respective semesters and collaboration.

Semester timeline (2017-2018)	EEP Team (The Sponsor)	ECE SD team (Engineering team)
First semester (Fall 2017)	EEP team begins.	N/A
Second Semester (Spring 2018)	EEP team's second and final semester.	ECE SD team's first semester
Third Semester (Fall 2018)	EEP team remains as an external sponsor, but *no class deliverables*	ECE SD teams finish with a completed product prototype

Table 1: Timeline for three-semester collaboration between EEP and ECE SD

The authors foresaw several learning outcomes and advantages of such collaboration for both teams. ECE SD team gets to work on a real-life problem that has been to some degree market studied and customer researched by the EEP team for a semester. A close collaboration formed between the business team and engineering team achieves higher success. EEP teams are forced to evaluate the technical skills needed to make their idea a reality. EEP team experiences working with a design engineering team like any other real-life start-up. The EEP team's opportunity to take the product to market is enhanced with the ECE SD team's final product prototype built after rigorous design and testing. Both teams learn multi-team management while keeping in conjunction with their own team goals and course expectations.

How EEP ECE SD collaboration works

First Semester (Fall 2018) **Aug 2018** EEP class begins. EEP students form teams and start generating project ideas and market research and customer study to test business viability. **Oct 2018** Each EEP team narrows down a project idea they	**Nov-Dec 2018** EEP teams are presented an opportunity to sponsor an ECE SD team starting the following spring. ECE SD and EEP instructors discuss the projects from the interested EEP teams and pick EEP projects which are suitable for collaboration with ECE based on the criteria above. These teams are contacted and upcoming ECE SD Spring 2019 – Fall 2019 scheduled is shared with them.
Second Semester (Spring 2019) **January 2019** ECE SD class begins. Several external entities submit their project ideas for ECE SD class. Selected EEP teams are part of this project list. These EEP teams pitch their project idea to ECE SD class along with other external sponsors. ECE SD teams are assigned by the ECE SD instructors.	**February to May 2019** EEP team fulfills the role of ECE SD team's sponsor. ECE SD team fulfills the requirements for the first semester of ECE SD (understanding product requirements, explore design options and creating the first proof of concept and mock customer prototype (2 design cycles). EEP teams fulfills their second semester requirements including complete business plan and a first proof of
Third Semester (Fall 2019) EEP team if desired still is involved with the ECE team as external sponsor guiding the prototype development based on market requirements and lessons learned. ECE SD creates a final prototype (through 3 design cycles) and demonstrates it via multiple milestones followed by test and verification. (First complete lab bench demo, Alpha Demo, Beta Demo and final prototype demo) ECE SD team hands off final designs and prototypes as guided to all SD teams to their sponsors.	

Table 2: Detailed timeline with milestones through one complete cycle of collaboration

Selecting the EEP teams (First semester)

EEP teams near the end of their first semester are presented an opportunity to become a "sponsor" of an ECE Senior Design team expected to start in the spring. The details given to the EEP class near the end of the first semester include (i) the benefit of participating in the collaboration, (ii) the eligibility requirements, (iii) how does the collaboration works, the timeline, and expected outcomes from it, (iv) the resources available to the teams to form a successful collaboration, and (v) the following steps if they want to participate. Once interested EEP teams approach the instructors, and then the teams are selected as potential sponsors based on three primary criteria:

(1) Need of the ECE skills to create the product for the EEP team's product idea.
(2) Scope of work and technical feasibility for ECE SD team to finish in one year,
(3) Quality of EEP team's market & customer study and business plan.

Selecting the ECE team as design and implementation engineers (Second semester)

Selected EEP team/s are invited to participate in the "pitch your project" event with all other external sponsors in the following spring semester to the ECE SD class. ECE SD team members are provided information about the EEP team (but not their prototype design) and the product concept. ECE Senior Design has a comprehensive method [1] to assign and form teams to work on offered projects. This method is described in detail by Gupta and Dunko in [1]. The same process is followed to assign a team to work on the project brought forward by the EEP team. In summary, the ECE team is formed based on the following high-level criteria.

(1) The design and engineering skills of the students required to fulfill the product requirements created by the EEP team.

(2) Degree of motivation and interest expressed by the ECE students to work on the project. Such motivation is gauged by submitted compelling reasons, matching backgrounds with the project domain/subject.

Founding rules for the collaboration

Funding

The EEP teams are funded by the College of Engineering with a fixed budget per team of $500. This budget is used for the EEP team's materials, supplies, and purchases for their prototype 1 and 2 as part of the EEP class. The teams are encouraged to raise funds beyond the approved $500 budget based on entrepreneurial approaches. The ECE SD program is funded by external entities called sponsors. The funding pool from all sponsors is used for materials, supplies, purchases for all ECE SD teams, lab equipment, lab maintenance, and event organizations. ECE SD program has maintained a separate funding pool (a certain percentage of the left-over external funding) to support unfunded individual and student projects. EEP team is considered under the category of student sponsors, and therefore the ECE SD team working on their project is funded by ECE SD program funds.

Design, Prototypes, and Intellectual Property

As per definition in both programs, the EEP team is considered the idea originator and thus owns the core concept and intellectual property associated with it. During the design and prototyping phase, if the ECE SD team comes up with a novel idea/method/process beyond the original core concept by the EEP team, all students who are legally inventors of that idea would be listed as co-inventors of the respective claims on the patent. Similarly, all ECE SD sponsors, including the EEP team, may require the ECE SD students to sign "Non-disclosure agreements" before sharing proprietary information, if any. Both teams are encouraged to follow different design paths. At the end of the ECE SD project, all sponsors, including the EEP team, will keep all the original design documents, design files, project code, and prototype designs generated by the ECE SD team as a sponsor. All the final physical prototypes are owned by the University and ECE SD program, donated to the ECE SD or EEP student team.

Initial observations and modifications

A pilot EEP ECE project was done in 2017-2018 (Fall 17-Spring 18-Fall 18.) Out of a total of eighteen EEP teams, one team was selected to be the Sponsor for one ECE SD team in the spring class of fifteen teams. Both (EEP and ECE) teams completed their goals for their courses. The EEP team delivered a complete business plan with a backing market and custom report with a preliminary prototype at the end of Spring 18. The ECE SD team took it further and delivered a robust final product prototype, including the product's detailed design document, final project report, test, and verification document, by the end of Fall 18 based on the EEP's product requirements team. Lessons learned from the pilot project were as follows:

(1) Both teams lost some time figuring out how to work together while maintaining completely different roles; the EEP team with the sponsor role and the ECE team as technical engineering roles. Both teams needed guidance in the project's beginning phases and a clear definition of both teams' roles and responsibilities.
(2) Both teams lost some time, in the beginning, to figure out how often to meet and how to schedule the meetings for all to meet.
(3) Assessments from both teams towards the other team needed careful attention. The attention mainly to understand their biases and expectations due to lack of sponsorship role experience.
(4) Teams struggle through deciding how much data sharing is ok not to affect the other team's performance, but at the same time not to lose the design variation in prototyping achieved by two different approaches.

Guiding and providing for both teams through the collaboration phase

To solve the above issues, the authors put together guidelines and rules to help both teams for future years (Fall 2018, Fall 2019). These rules/policies/guidelines are formed to ensure both teams (EEP and ECE SD) get a fulfilling experience; however, none of the teams get an undue advantage over the other teams in their respective classes. These rules also help the EEP team

with their "sponsorship" role for the ECE SD team since, for most of them, this is the first time they have been in this role.

Grading and assignments

Both teams must complete their respective class deliverables based on their respective instructors and class rubric. Both teams are graded separately based on the individual course policies and assignment rubrics by their respective instructors. Neither of the teams can assist the other team with their class assignments or graded project deliverables as part of their course syllabus (Please see the list of assignments in the introduction). E.g., the ECE SD team cannot use the EEP team's market report as is to complete their primary market and technology report for SD class. However, instead, EEP teams can act as an information resource by sharing important market data collected by them with the ECE team to drive the product direction. Such information sharing is equivalent to the sponsoring company sharing customer or market data to explain its features and game plan to the engineering team. Both teams are also highly encouraged to follow different design paths towards their final prototype's feasibility within the set product requirements. Since the EEP team is not allowed to share their design solutions with the ECE SD team, many times completely different design solutions will automatically emerge. Both teams are allowed to share lessons learned and tips from their design solutions as per the guidelines. Beyond project deliverables stated in the section introduction, both EEP and ECE SD programs have other intangible grading aspects such as "teamwork and professionalism," "customer and client interaction," "meeting preparedness," etc. Both instructors determine these through status reports, assessment surveys, and instructor observations through client meetings and reviews. The format and frequency of these surveys differ based on each instructor's course syllabus and policy.

All ECE SD teams do a total of four team/individual/sponsor assessments. ECE SD team's comments about their sponsoring EEP team are studied/evaluated for consistency by both instructors and, if necessary, considered as part of their final grade for the EEP class. On the other hand, all ECE SD program sponsors, including the EEP team, are requested to send their assessments of their teams twice a semester. The comments are considered part of the ECE SD team's professionalism grade with instructor observation, similar to all other sponsors.

Project planning and mentoring

Teams are encouraged to share their project and class schedules in the beginning, to keep each other informed of significant project milestones, and schedule meetings accordingly. Both teams are encouraged to pick team liaison/s who would meet with each other and exchange needed information to make the meeting-scheduling easier and meetings more productive. All teams are, of course, welcome to meet with each other whenever necessary. The ECE SD instructor will fulfill the technical mentor's responsibilities for the ECE SD team since the EEP team is not expected to provide the team's required mentor. The EEP team representative/s will be expected to attend the ECE SD team's demonstration milestones and design reviews just like any other

sponsoring company representative. Suppose the EEP team does not want to continue being involved in the third semester after their course ends in the second semester. In that case, the ECE team will continue the project prototyping and final presentations as required by their course requirements.

Outcomes of the EEP ECESD collaboration

Two more EEP teams participated in the program in the Fall 2018-Spring 2019-Fall2019. Both EEP teams and ECE teams provided very positive assessments and learning outcomes of the collaboration. The effect of the partnership on the EEP team based on author observations through team interactions and surveys was impressive. It provided the EEP teams an increased incentive to document and convey product ideas and features to the ECE team and increased motivation derived from the extra attention and design work developed by the ECE team. ECE SD teams working with respective EEP teams also benefited significantly from this collaboration. Both SD teams were voted the top two ECE senior design teams in the fall of 2019 (a total of fifteen externally sponsored teams). One of the projects was awarded "Best project design of the year" by industry judges on ECE Design Day 2019. Both projects are described in the appendix. Due to the success, EEP and ECE SD collaboration was funded by the College of Engineering in 2019 to support more collaborations and move towards more multi-disciplinary design teams. These funds were used to support both EEP and ECE SD teams which are participating in the collaboration.

Other learning outcomes

ECE SD team appreciated having worked on a real-life problem that had been market studied and customer researched by the EEP team. EEP team found the experience of working with a design engineering team like any other real-life start-up very valuable. The ECE SD team's final product prototype built after rigorous design and testing better represented the EEP team's concept and more useful for investor presentations and kick starter building. Both teams got significantly better at multi-team management, project planning while keeping in conjunction with their own team goals by the end of the course. The EEP team also reported a boost of confidence, a feeling of reality, and the existence of the ECE team's effort boosted the credibility of their project idea.

The teams which were part of the third collaboration round in spring 2020 were hampered significantly by the COVID-19 pandemic. The project was reduced in scope to be completed within the constraints of a remote working environment. Both teams struggle with motivation due to uncertainty, reduced campus access, and other pandemic-related personal and social issues. The authors have not yet assessed all the aspects of the third round in depth.

Major learning lessons

Following learning lessons were observed by the authors through all three cycles of collaboration.

1) Though EEP supports students from multiple disciplines to form a team, like any real-life problem-solving project, EEP teams' project ideas tend to need skills beyond various disciplines of members in their teams. For this collaboration, the authors select the EEP project ideas that need the most ECE domain knowledge. However, there is always some aspect of the project beyond the reach of the EEP and ECE team's capabilities. This observation gave rise to setting the foundation of genuinely multi-disciplinary teams instead of simply a group formed by students from multiple departments.

2) All EEP students' motivation at the beginning of the project ideation and near the end of their class (investor presentation) significantly differed. Some of the reasons are difficulties in starting a successful start-up, lack of funding, competitive start-up market, graduation pressures, full-time jobs, etc. Such problems significantly affected their involvement in the ECE team in the third semester near completion.

Impact of this collaboration towards the Multidisciplinary Design Program

After observing this collaboration's success and failures, the next step was to expand the engineering team (ECE SD) to a multi-disciplinary design team by seeking and including students with skills required for the project at hand from other engineering and sometimes non-engineering departments "independent design study" students. In finding ways to recruit students from other departments, authors realized that almost all departments offer independent studies or research study classes where students are encouraged to work on a separate project (team or individual) and get credits and experience. These credits also count towards their degree.

Based on the selected EEP team's project requirements, authors identify the specific skills and domain knowledge needed from other departments beyond ECE (engineering and non-engineering). The project background and skills required are advertised to the relevant departments to seek students with the right skills to be part of the EEP ECE collaboration team. Other ECE SD sponsors are also encouraged to identify skills needed beyond ECE to recruit students with the right skills from other departments. Since fall 2018, the authors have successfully formed need-based multi-disciplinary design teams, including mechanical and aerospace engineering, textile engineering, industrial engineering, biological and agricultural engineering, and computer science. Many of these teams have worked with other non-engineering groups and students such as phonetics laboratory, College of Natural Resources: Department of Forest Biomaterials, College of Agriculture and Life Sciences, and Veterinary School.

This action forced EEP teams to evaluate all needed disciplines to make their project idea successful. It also provided a reality check for the idea's feasibility as a business. All teams realized the significance of the multi-disciplinary nature of any real-life problems and learned design elements of another engineering discipline.

The impact of this action was beyond EEP ECE SD collaboration. Currently, ECE is the largest engineering department in the college of engineering. ***Table 3*** shows the distribution of capstone design teams as part of several departments in the college of engineering. More than 220 teams in 10 or more engineering programs at NC State College of Engineering have one or two semester-based single discipline senior design programs. EEP is the only capstone program that supports students from all departments to form multi-disciplinary teams. And as stated before, the multi-disciplinary nature of the EEP teams is only suggested and often occurs due to their way of formation (students from various departments want to form a team together) and not necessarily based on the project needs. ECE SD program has approximately 50 projects every year. Because of this collaboration and its side effects, around 7 to 10 of these design projects (15-20%) are genuinely multi-disciplinary and growing. These projects are mentored by 6-8 faculty members from several departments. These projects' standing in class is in the top 20 to 30%. The growing multi-disciplinary collaboration has brought $50K in funding since 2018 from internal and external sponsors. They see value in funding projects where students from multiple relevant disciplines build their solutions.

Capstone Design Programs in College of Engineering	*Approximate Number of teams/year*	*Nature of the program*
Electrical and Computer Engineering	50	Two semesters (forty single discipline teams and ten need-based multi-disciplinary teams)
Engineering Entrepreneurship Program	20	Two-semester multi-disciplinary teams
Chemical and Bio-molecular engineering	19	Two-semester single discipline teams
Computer Science	22	One semester single discipline teams
Industrial and Systems engineering	20	One semester single discipline teams
Nuclear engineering	7	One semester single discipline teams
Material Science engineering	12	One semester single discipline teams
Mechanical Engineering	45	Two-semester single discipline teams
Textiles engineering	16	Two-semester single discipline teams
Paper Science and Engineering	10	Two-semester single discipline teams

Table 3: Distribution of senior design teams in various engineering departments in the college of engineering.

Next steps

The authors plan to create a detailed quantitative assessment study to assess multi-disciplinary team's performance (EEP/ECE collaboration and beyond) versus the traditional ECE team's performance on various aspects such as technical design merit, product feasibility, teamwork, project motivation, etc. Based on the assessment outcomes, the model can be improved in the timeline, needed team resources, additional teaching topics, change in rubrics and deliverables, collaboration guidelines and rules, etc.

The authors plan to adjust the current model to solve the problem stated as the second major learning lesson. Model adjustment may include providing extra resources to the EEP students to benefit after graduation, changing the collaboration timeline to two semesters (instead of a three-semester) to keep both teams' motivation near the end of the project high. A change in timeline will need careful consideration based on project stages as part of this collaboration.

The multi-disciplinary projects are still part of the core ECE SD program mentored by several faculty but taught mainly by ECE instructors. Authors wish to adjust the current model to create an infrastructure for a proper multi-disciplinary program separate from the traditional ECE SD program with topics and learning outcomes beyond ECE design. The authors also explore merging parts of all conventional design programs in engineering departments (listed in **Table *3*** and beyond) to form multi-disciplinary senior design teams to solve unique problems with various approaches and mindsets.

Conclusion

The creation of collaborative design projects between the Engineering Entrepreneurs Program and the Electrical & Computer Engineering Department's Senior Design program proved to be a key aspect in teaching both EEP and ECE teams who desire to be part of the collaboration program, essential learning outcomes such as multi-team management, project planning, real-life experience in sponsorship/mentorship, presentation to a broader audience, rigorous prototyping, etc. The authors learned from the pilot project and created a model, rules, and guidelines that can be extended to other multi-team and multi-disciplinary collaborations. The model, student assessment, and feedback gave rise to ideas and opportunities to create a multi-disciplinary engagement platform for students and faculty in other departments in the ECE Senior Design program. Using this model, the authors showed significant improvement in teams with multi-disciplinary projects and sponsor funding.

The project's next steps are to study and quantify the performance, improve the model to make it scalable and modular, and include several engineering and non-engineering departments to create a true and separate multi-disciplinary design program.

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Appendix

This section describes the two projects, "QwikFill coaster" and "Rent-a-Rella," which were part of the second year of this collaboration and were funded by the College of Engineering teaching faculty support award.

Project 1: QwikFill coaster

Problem Background and the need

The pain point that we are targeting is the amount of time spent waiting between refills at a restaurant. It will eliminate the need to flag down a waiter and ask for a refill by restaurant patrons. In terms of other benefits, we expect the tips to be higher as customer satisfaction increases.

Problem Description/requirements

- Build a coaster that will sense when the cup is running low and send a message to the staff notifying them which table needs refills.
- The system needs to account for different cup sizes and materials (glass or plastic) and allow each establishment to calibrate it based on what they have.
- An easy-to-follow program will need to accompany the hardware to allow the serving staff to keep track of the drinks.

Project 2: Rent-a-Rella

Problem Background and the need

Rock-n-Rella provides students with umbrellas for rainy days when they are unprepared. Rather than running from class to class and getting wet, students will be able to check out an umbrella and cover themselves for the duration of the storm. The United States has over 4,600 colleges and universities and over 20 million college students, so there is a vast potential market.

Problem Description/requirements

- Small kiosks will be located in buildings and parking garages across campus.
- Each kiosk will store a few dozen umbrellas.
- Students can swipe their student IDs to rent and return umbrellas.
- We keep track of who has an umbrella checked out and how many umbrellas are at each kiosk.
- Mobile app displays kiosk locations and many umbrellas at each site.