Modernizing Capstone Project: External and Internal Approaches

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Abstract

Capstone projects are an important learning experience that gives students the opportunity to gauge how to apply what they have learned in a real-world environment. Traditional approaches have embedded students in industry where often, well-defined self-contained project are the focus. The lack of critical-path projects is necessary, as companies cannot risk their competitive advantage to afford students a cutting-edge experience. A common drawback to industry experience is that it can become difficult to clearly determine performance as goals can change and projects re-defined when students struggle and mentors assigned to them either don't want to see students fail or lack the time to fully invest their attention on them. Another approach to Capstone projects is to internalize the experience by creating faculty led projects that focus on relevant work. This can manifest itself in research projects for undergraduates where the work that students do directly impact work of the faculty. A positive outcome is that this, by its nature, immerses students in a real-world experience as the research outcomes are not only a means to vet student competencies but are relevant to the work that faculty do for their own scholarship. Though a drawback may be a reduction of exposure to a wider range of emerging technologies one expects from industry, with that type of faculty engagement, and in an academic setting, perhaps a more robust Capstone experience can be achieved.

In the Applied Engineering and Sciences department at the University of New Hampshire at Manchester, which offers degree majors in computing and engineering technologies, both types of Capstone experiences have been explored. With its urban setting as a commuter campus in the largest city in our state, the college is ideally situated to work with industry partners in the area. Its engineering technology programs have successfully hosted senior Capstone projects for over 25 years, while its computing programs have similarly hosted professional Internship experiences for over a decade. Over the past seven years computing has introduced an undergraduate research project to augment the Internship experience with relative success [1], [2] and engineering technology has introduced options for its seniors to work in internally funded projects as well [3]. This paper will compare and contrast these two techniques of providing students with Capstone project experience to highlight the pros and cons of each. With a mix of both industry experience and faculty guided work, the aim is to provide an optimal approach that benefits students, industry partners, and faculty involved in this very important element to four-year educational degree program.

Introduction

The University of New Hampshire at Manchester (UNH-M) offers degrees in both computing and engineering technologies in the Applied Engineering and Sciences (AES) department. The college is part of a larger university and being an urban commuter campus, its mission is as much on giving students real-world experiences as it is on providing a sound liberal arts education. With a setting in the largest city in the state, many opportunities arise for students to enhance their post-graduate skills with an extensive professional development curriculum. With over 25 years of history supporting Capstone, faculty members in the AES department have formulated several approaches to this professional development. From a more traditional approach of hosting a semester long project where students are embedded with industry partners, to individual or small group projects either with a faculty member or a professional, to a research project with a large team working on cutting edge research, students in the AES department at UNH-M have been exposed to one or more of these activities before graduating.

Following a literature review of the related work, the next sections of this paper will present the various forms that Capstone manifests itself at our institution, providing both detail and context in how it fits into the particular major. The disciplines represented, engineering and computing, are both in the applied realm and have been formulated with professional practicum from the onset. For engineering majors in the Engineering Technology (ET) program, offering both Electrical Engineering Technology (EET) and Mechanical Engineering Technology (MET) degrees, most students spend a semester embedded with a company, working on a well-defined project while a smaller number work with a faculty advisor or professional on an internal applied research project. For computing majors in the Computing Technology (CT) program, offering Computer Science (CS) and Information Technology (IT) degrees, students experience both an external setting through a one-semester Internship with an industry partner and an internal setting through the undergraduate research Capstone project, a team effort with an annual enrollment of about 20 students all presently working in speech recognition.

Literature Review

The proceedings of the American Society of Engineering Education (ASEE) and the Association of Computing Machinery (ACM) databases were used in the literature review of this work. The titles and abstracts were searched with the keywords *capstone* and *internship*. The case studies of this paper concentrate on describing the implementation of Capstone projects but include Internship, another form of professional development, for an interesting comparison.

Over the period examined the ASEE database shows an increase in scholarly papers both with keywords *internship* and *capstone,* with *capstone* being slightly higher in frequency. In 2017 the ASEE database had 50 papers with the keyword *capstone* and 21 the keyword *internship*. In the ACM database, it was observed that from 2011-2015 there were more papers with the keyword *internship* than *capstone*. In 2016 there were equal amount of scholarly papers between Capstone and Internship with 2017 slightly more Capstone papers, with 12 and 11 articles respectively. This does not suggest that Capstone projects are more prevalent than Internship in practice but does suggest that former is gaining popularity as a research topic for scholarly journals and proceedings.

Three common themes were observed among the Capstone project literature reviewed. 1) Papers examining Capstone projects over a period of time, typically many years or decades, across multiple institutions and disciplines; 2) papers that describe various models of executing projects; 3) papers that examine specific examples of Capstone projects at a single institution.

From what was reviewed an example of a series of papers implementing surveys started in 1994 by Todd and Magleby et al. [4] that was followed up by Howe. S. et al. in 2010 [5] and 2015 [6], [7] respectively. The work from Howe, which can be found in the ASEE database, is more recent and relevant to this work. In 2015 Howe did both a qualitative and quantitative analysis of survey results from 256 ABET accredited institutions executing Capstone projects in 464 distinct departments for a total of 522 respondents. This work looked at many aspects of the Capstone experience. One interesting reported observation was how various programs and institutions valued “process vs. product” in the final outcomes of a Capstone experience. Howe also examined the number of semesters to complete, age of Capstone program, faculty involvement, topics covered in lecture, average number of students per project and number of distinct projects per Capstone project cycle.

Several examples of literature describing various models for executing Capstones looked at the benefits of taking a multidisciplinary approach and engaging industry partners to help facilitate student projects. The work by Reyer, J. described an “Industry Based Model” [8] and examined various metrics for team evaluation, team assignment, team building, and implementing gateways to promote meaningful progress. Reyer also described the possibility and consequences of students failing a Capstone experience. Goldberg, J. looked at industry involvement in a multidisciplinary Capstone design course [9]. Goldberg’s paper investigated dealing with issues such as NDAs and IP ownership as well as examining if student grades should be generated from the industry partner or from the faculty. An interesting observation for the Capstone program Goldberg describes is the division of faculty on the overall value of using industry partners in the Capstone experience.

Two instances of scholarship that looks at specific examples of executing the Capstone experience were Shin Ha, S. from Virginia Military institute and Flowers, J. from the University of South Carolina. Both of these papers are from the ACM data base; the Shin Ha paper looks at three specific software Capstone projects from two institutions in the same system [10]; the Flowers paper is a student paper reflecting on a Capstone experience with the purpose of suggestions for improving the experience. The contrast of the ACM literature and the ASEE literature is that software projects tend to be more focused on design and verification, where the engineering papers tend to have more focus on process such as funding and project launch. In both the ACM and ASEE literature review it was most common for Capstone experiences to span two semesters with some literature suggesting that going to a two-semester program would be beneficial [11].

In the literature, the following common question groups were observed, and informed the analysis and narrative of the case studies in this work:

- **Project format:** How are projects assigned? Are students working independently or in teams? Is there an industry partner? Or faculty advisor?
- **Project content and goal:** Is the project process or product focused? Is there cross discipline collaboration such as between computing and engineering?
- **Credit hours and accreditation requirement:** How many semesters/credit hours? Is the Capstone course used for accreditation assessment purposes?
- **Outcome evaluation:** What are considered "successful" outcomes? What are the reflections on the overall experience, takeaways pro's and con's? Are metrics tracked from the Capstone experience used for a continuous improvement process?

Case Studies

This section will present case studies that cover the different types of professional development mechanisms as shown in Table 1. These case studies are experiential in nature, describing both the expected student experience and, where applicable, deviations from the expected. The case studies include observations we as faculty have made both on the benefits of the various types of methods used as well as pitfalls and improvements to enhance student outcomes further. Finally, we draw conclusions on both the current state of Capstone at UNH-M and how we intend to proceed forward.

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Table 1. Five Case Studies of Capstone experience for our programs under different models.

Case Study 1: An External Project in Companies with Existing Partnership

The UNH-M ET program has been ABET accredited since 1980. A key component to gathering assessment data to ensure student learning outcomes are met is its Capstone project class. The Capstone class is a two-semester class starting in the fall semester of the student's senior year. The class is four credits a semester for a total of eight credit hours. The fall semester is focused on getting students assigned to projects. The first semester students are required to select a project, identify a sponsor, write a draft proposal, do an oral presentation on their project, conduct a literature review, maintain a project notebook and submit a final written proposal at the end of the semester. In the spring semester students must provide an update the first week of classes after the winter break along with an interim evaluation from the sponsor. Also, during the spring semester students are required to give updates on the projects during class, write a final paper and to participate in UNH-M's Undergraduate Research Conference with a twenty-minute talk and a poster presentation on their projects.

The ET program has had long-standing relationships with many industrial partners, including the one discussed in this work. For more than a decade this particular partner has hosted one or two students per year for Capstone projects. Due to the nature of the company's business, the manufacture of reusable touch fasteners, most all of the projects have been related to the MET portion of the ET program. There are several factors that appear to contribute to the success and longevity of this relationship. These are largely related to the familiarity between the company and the university. The company is headquartered in the community and has a significant number of employees who are alumni of UNH-M, some from the ET program. The company is involved with our institution, including serving on the ET program's Industrial Advisory Board. Often, ET program alumni have been sponsors for the Capstone projects. However, in recent years, opportunities have been recognized to improve Capstone project outcomes for both the host company and for the students. The successes and opportunities for improvement are discussed briefly below.

It is believed that an important part of the relationship between the ET program and the industrial partner is that they are familiar with the demographics, culture, and needs of the students, and with the somewhat unique nature of our program. A few key points are:

- The program is the Bachelor's component of a 2+2 program. An admission requirement to the program is an Associate's Degree in a field that gives adequate preparation for studies at UNH-M.
- About half of the students pursue their degrees full time, and earn their Bachelor's degree in two academic years. Others are working full time and working on their Bachelor's degree on a part time basis and take four or more years to complete the degree after the Associate's. Often there has been a gap of some years between completing the Associate's and entering the Bachelor's program.

- The ET program serves a large number of non-traditional students. Many are first generation and there are some military veterans. Ages of the students in the program range from the early 20s to late 50s. On account of this age range, several students have worked for a number of years. Many of the students have significant family responsibilities. Almost all have been long-term residents of the region and are committed to staying in the area after graduation.
- The company is very familiar with the more applied focus of ET programs, and chooses Capstone projects that are good fits for ET students. Further, it recognizes the need for the students to complete their degrees within the constraints of the academic calendar, and scopes projects accordingly, and adjusts the scope when delays are encountered.

The host company is a well-known manufacturer of these reusable touch fasteners and serves a wide customer base including private consumers, commercial companies, and the military. Applications of the product cover a wide range of industries. In some instances, the end customers have stringent requirements for the quality of the product. While the product in and of itself may not initially elicit a lot of excitement from students, the Capstone projects hosted by the company have several attributes that have the potential to produce high-quality outcomes. These attributes include:

- The projects are in areas that are of strong interest to the company. At times the project has been related to something of interest to the top management. At the same time, the project is not part of a critical path. Failure of the project will not have a significant adverse impact. The projects are hosted within the R&D area, although the students have visibility of how their work can contribute to the manufacturing of products. In the early stages of the project, the students engage in hearing the "voice of the customer", and thereby become acquainted with why their project matters to the business.
- The scope of the project is carefully chosen by the company, so that if the students make good progress they have the opportunity to both design a piece of machinery, and have it built and assembled.
- The students are given office space within the hosting group. Although the projects are unpaid, the students are brought onboard in a manner similar to the other employees. Because the company faces significant competition in the marketplace, there are significant considerations for the protection of intellectual property and the students enter into non-disclosure agreements. It has been observed that the students tend to feel they are part of the team and develop collegial relationships.
- Based on the strength of their performance on Capstone projects, several students have been hired as full time employees following graduation. The positions these graduates have obtained have competitive pay and benefits, and come with position titles that do not distinguish ET degrees from more traditional engineering degrees.

Despite the many attractive attributes of the opportunities, in the past few years some classes of students have shown limited interest in the Capstone project opportunities offered by this sponsor. In some instances, due to distance, work or personal obligations, or lack of commitment, students have not fully engaged in the projects and have fallen short relative to expectations. In an effort to overcome these issues, some success has been had with a new approach to seating students in Capstone projects with this sponsor. Since the company has longer term interest in UNH-M graduates than just the duration of a Capstone project, and effort has been made to engage students early. The approach taken has been to offer Internship opportunities in the junior year to students who appear to be potentially good candidates for a Capstone project. So far this approach seems to be working well. The conclusion drawn from this brief case study is that even with strong partnerships with Capstone project hosts, it is good practice to review the processes as student needs and interests evolve relative to project opportunities.

In terms of the questions identified in the literature search section, the characteristics of the professional experience described in this case study are summarized in the bullet points that follow. These reflections include both items related to the external industrial sponsor in the case study, and also more general reflections about the Engineering Technology Program as a whole.

- **Project format:** Projects are assigned to students (either individually or in teams) through a combination of sponsor and faculty input. The sponsor defines the scope of the project and has the primary decision-making authority in choosing students. The faculty's role is primarily in helping to screen candidates from the students who have expressed interest in the projects and act as liaison. In the past the matching of student to project began in the early part of the fall semester of the senior year. More recently, the sponsor has asked the faculty to help identify students to be offered an internship in the summer between junior and senior years.
- **Project content and goal:** The projects are largely focused on process. Even though sponsors are adept at picking projects that can result in a product, it is recognized that there are factors in an external collaboration that can strongly affect project execution.
- **Credit hours and accreditation requirement:** Assessment of outcomes from the ET Capstone experience plays an important role in accreditation. The Engineering Technology Capstone experience at our college comprises 8 credits earned in a two-semester sequence.
- **Outcome evaluation:** Successful outcomes include, but are not limited to, students improving their technical skills, experiencing real-world application of technical disciplines, working collaboratively with others, and gaining experience in technical communication both oral and written. One of the important pros of the Capstone portion of the MET program is the potential for a high-quality experiential learning with strong ties to how a project unfolds, especially with sponsors sensitive to scoping projects that

can be carried to a reasonable conclusion in the relatively short time. Potential cons in general are that the quality of experience can vary significantly from sponsor to sponsor and the lack of student comfort with some of the ambiguity involved with projects.

Feedback from sponsors drives continuous improvement of the Capstone process with end-of-project evaluations. The sponsor evaluations play a role in both the grading of the project, and also providing suggestions for improvement. Reflections on the value of the Capstone project is incorporated into exit interviews that each student is invited to complete a few weeks before graduation.

Case Study 2: A Hybrid External Internal Project

A variation on a successful ET Capstone project that created a hybrid approach to an external partnership with an internal one was a collaboration between the ET students, CT students and a small local engineering firm that had sponsored projects in the past. This project was funded by external local government sources intended to help small business in the state be competitive and to encourage collaborating with the faculty at UNH-M. The funds were intended to pay students and faculty with stipends and to offset the cost of prototyping materials, the company offered in-kind services.

The project was to develop and prototype a remote wireless network to collect environmental data in an extreme weather environment. The project consisted of mechanical design of packaging, electrical design of the system and sensors and the software design of the databases and user interfaces. The main risk was the scale of the company; it was a small privately-owned firm with limited resources, very tight budgets, and thin operational margins. The company stated it needed to make the product commercially available after the end of the academic year to be profitable. The company's business plan stressed rapid time to market and to provide ease of use of the system to the final customer. For a successful project from the company's perspective, a working solution needed to be delivered that could be manufactured after two semesters.

The students were divided into two teams. The first was the electrical team, and the second the computing team. There were two students on the electrical team and three on the computing team. The business owner took the role as project manager and two faculty members, one from ET and one from CT, participated in an advisory role. Weekly meetings were established and students created work breakdown structures for their particular tasks. The electrical team was tasked with designing power, communication, tracking and data logging systems. The power system needed to be remote and not need a dedicated electrical outlet. The GPS system needed to interface with the software system to allow for real time location of the devices on a Google map interface. The communication system was implemented using Wi-Fi that allowed multiple sensors to communicate with each other as measurements were taken and transmitted data back to the software system. The software system consisted of a database to store measurements and an on-line GUI to look at the data. The mechanical system and housing were designed by the company owner.

For the electrical system the hardware was based on an Arduino platform. Designing with Arduino can be fast and inexpensive but its foundation is deeply based in an open source platform. Shields for XBee Wireless and GPS along with sample code are widely available. Once a solution is found prototyping with an Arduino a tremendous amount of development needed to be done to appropriately protect the sponsor company's intellectual property and to honor the nature of licensing open source code. For the power system there was much more testing of various charging systems, solar panel configuration and battery chemistry than was anticipated. Of particular challenge was the system was to be deployed in an extreme weather environment and needed to function reliably without interaction for many years in places where temperatures could drop to -30 degrees Fahrenheit sustained for weeks at a time.

For the software systems a lot of work was done in getting the features in the user interface how the company wanted. There were also issues with the software about using low cost open source tools and the ability to ensure the security of the data collected and sensitive customer information. The software team developed the following solutions. A ConnectPointX Gate way to interface the WiFi device which provided the IP network connectivity for end-point devices in the wireless XBee networks. The gateway collected the end node data, processed it, and sent it to the software system using a LAN connection. A cross-platform Apache, MySQL, and PHP run-time environment were developed from managing the database with relational tables that store measurement data (latitude and longitude, load sum, temperatures, and status and diagnostics parameters) for each monitored station. A backend software system, A PHP server application was implemented to request data from the wireless network & sent to the database. Web and mobile client applications provided the following functionality: allow users to enter station parameters, represent overlay colorized station locations (using GPS), colors indicated, plot measured load, temperature(s) and building load limit vs. time (selectable time scale, i.e. day, week, month, years, etc.) for any station, and send alert messaging (text and email). For the software team there was less debugging than for the hardware but a lot of interaction with the company was need to finalize something so that the databases and GUI's met all the design requirements. There was also concern about legacy systems once the students left the project.

This project was intended to complete in one academic year. It was understood by the company that most of the students would be graduating and starting professional careers after the completion of their degrees. In the fall semester proposals were drafted and aggressive schedules were put together. By the winter break working prototypes of all three systems, mechanical, electrical and software, were demonstrated. It was the hope of the company to be ready to manufacture at the conclusion of the spring semester. As with most student projects, issues slowly started to materialize that would impede demonstrating a commercially ready solution in the time frame desired by the company.

By the end of the academic year, a fully functional software system was demonstrated. The electrical system was still very much in a prototype state but three remote stations were functional. The students had such a great experience that much of the original team volunteered their time to work on the project after graduation. By the next academic year a second prototype of the electrical system had been built. The company hired contractors to supplement some of the printed circuit board design. By the third year three of the systems were sold commercially and is now offered as one of the main product lines of the company. From an academic standpoint this project was very successful and a great model for getting students hands on real world experience developing commercial grade systems at the undergraduate level. It was obvious once the project was underway that the perspective of a successful academic project and a successful commercial project are very different. For the student the focus was on meeting the Capstone project requirement of the program, for the faculty it was nurturing relationships for collaboration and scholarship, for the company it was competiveness and profitability. This work demonstrated a great balance of the three perspectives and is a model the ET program is using on current and future projects.

- **Project format:** In the context of this study this project was assigned by the faculty to the students based on student past performance. This is a great example of using an industry sponsor and with strong faculty support.
- **Project content and goal:** This project was an even mix between process and product, observing the students surprise at the amount of process needed to successfully launch a commercial product. The nature of the project was very interdisciplinary crossing between, software, firmware and hardware.
- **Credit hours and accreditation requirement:** The course was two semesters for 8 credit hours. Several learning outcomes and educational objectives were documented in the course syllabus and assessment data was collected and monitored.
- **Outcome evaluation:** Overall this was considered a “good” outcome in that the company is now selling commercial products. Reflecting on the project there was an obvious disconnect between the industry partners expectations and what a student team could realistically accomplish in two semesters. The students did deliver a working prototype in the time allotted but the company needed to hire contractors to get a product that could be manufactured. For future projects more care is taken to make sure sponsor companies understand the nature of student work and level set expectations from the start.

Case Study 3: An External Project in Companies with New Partnership

External projects from newly established industrial partners often fall into the category of non-research development projects. In the fields of IT and CS, students are usually placed in an existing software development team or in the company’s IT department to work on projects such as IT system integration. Since the partnership with the companies is new, the students and their faculty advisors are usually not familiar with the product or service offered by the company, or their existing software environment and tools. Nonetheless, such projects are valuable for students as they explore career options and for faculty members to establish new relationship potentially leading toward further industrial collaboration.

Students in such external Capstone projects usually do not know the nature of the projects in advance, nor do they have much choice over the job duties assigned to them. They are more likely to be put in non critical-path projects, as companies may not want to invest in their training or to risk their competitive advantage to afford students a cutting-edge experience. Moreover, students joining an existing project can find it overwhelming to learn the company's software development environments, tools or even just the technical jargons.

Another potential drawback of such external industry project is that it can be difficult for the faculty advisor to assess students' performance. Since the relationship with the company is new, faculty advisors usually have limited knowledge of the project content and personnel. There can also be large variations of job responsibilities across different companies and different projects, making it even harder to determine how well the academic learning goals are being accomplished. Faculty advisors may not be able to invest their attention over the full course of the Capstone project, and thus have to rely on students' work log and company's evaluation report to determine the Capstone project outcome.

These challenges associated with external industrial projects are addressed in our IT and CS program through a well-structured Internship project course. Each student is given a set of individualized learning outcomes, which are clearly defined by both the faculty advisor and site supervisor. The faculty advisor keeps track of each student's work progress through a weekly work journal that includes detailed items such as work summary, reflections and planning. The faculty advisor will then provide feedback to the students, and which helps them resolve difficulties and serves as a basis for outcome assessment. Moreover, eliciting feedback, such as a midterm evaluation, from the site supervisor during the project can be used effectively by faculty members to better monitor students' progress and to ensure they are on track toward a successful project completion. The Internship project course fosters a supportive and collaborative environment through regular face-to-face group meetings in which students share their work experiences.

A senior IT student in the CT program recently completed an external project in a company widely known for their focus on development of innovative solutions and advanced technologies. The company consists of multiple project teams across a diverse set of applications, each consisting of engineering, design, manufacturing and quality professionals. It was the first time the CT program collaborated with this company through an Internship project. The faculty advisor had very limited knowledge of the project, which was under a strict non-disclosure agreement that prevented the student from discussing crucial parts of project. The student produced weekly work journals but had to omit many technical details of the new invention.

During the group meeting in the project class, the student was able to share the activities accomplished during the project but only at a very high-level. Even though the faculty advisor had no knowledge of the actual product the student worked on, it was evident through the face-to-face group meetings as well as the work journal that the student had successfully fulfilled the expected learning outcomes. The final project assessment also took into consideration inputs from the project site supervisor. Shortly after the project's completion, the student was offered a full-time developer position in the company with the same project team. The company also expressed strong interests in further collaboration with the CT program through hosting more students within our Internship project course. The conclusion drawn from this case study is that well-structured course guidelines, individualized project goals and frequent feedback from the hosting company are crucial in the successful completion of Capstone projects with new industrial partners.

In terms of the questions identified in the literature search section, the characteristics of the professional experience described in this case study is summarized below.

- **Project format:** As the projects are new, students select the project based on a very brief description of the project. Students often work in a team and having an industry partner to be their main project advisor.
- **Project content and goal:** The project is often process focused. Cross discipline collaboration is not a requirement but encouraged.
- **Credit hours and accreditation requirement:** The CT Internship experience course at our college comprises 4 credits earned in a single semester.
- **Outcome evaluation:** The evaluation of student learning outcome is challenging in such projects since the faculty advisor often is not directly involved with the project. It is essential to have a structured and individualized evaluation scheme while maintaining frequency interaction with the students and the supervisor at the hosting site.

Case Study 4: An Established Internal Research Project

Undergraduate research is an active field of study in computing education and has demonstrated the ability to engage students to see beyond their course work. Natural forums for this research are Capstone projects. For computing majors at UNH-M the final professional development experience they face is a semester long research project in speech recognition. Over the past six years the project has hosted between 19 to 22 students each semester. It has been a challenging and engaging experience for students, one that consumed more of their time than any other course in their computing major. The challenge of learning in a difficult field of speech recognition inspired many students to go beyond what they thought they were capable of. With a mix of students from CS, IT and a small number in Computer Engineering Technology (CET), the project has drawn from the various strength of the different variations of computing majors.

The project adds little structure for students. At the start, students are asked to chose one of 5 groups and are divided as evenly as possible. Each group focuses on one particular task:

- Systems group – focus is on servers used for speech processing
- Experiment group – focus is on the experimentation infrastructure
- Data group – focus is on the large data set used in building speech models
- Software group – focus is on understanding the speech tools software
- Modeling group – focus is on leading the research effort in speech model building

Some of these groups better align to specific majors. For instance, CS majors are put into the Software group and are asked to organize and understand the code base. In its latest iteration of the project, the Software group's responsibility focused on one of the main elements of a speech system, the decoder. They were tasked with analyzing the code base to understand the technology enough so they could assist in its alterations. Prior to this, most work focused on organizing data and using the set of speech tools as provided[1]. The Systems group is a good fit for IT majors, allowing students to focus on server software. Both the Data and Experiment groups also tend to lend themselves to the organizational and analytical expertise that our IT majors are trained with. The Modeling group is challenging for any major and in many iterations of the project it attracted those students that were excited in the research aspect of the project. Note however, that although the Modeling group focused on how the speech system worked, how it was trained, and how it was used, every student need to have a rudimentary knowledge of this so every student needed to do their own modeling in some capacity. The Modeling group's purpose was to look not only at what was there but also at how to add new technologies to the system.

At the halfway point of the semester, two teams were created, with each team made up of half of each of the groups so that both teams had specific expertise in all 5 areas. The purpose for teams was to compete to come up with the best set of speech models, as the goal of the research project for the first few years was to build an optimally-tuned speech system and create a world-class baseline with the given data set. This was to then lead to actual improvement in the technology with new ideas from the faculty member leading the project. Without an optimally tuned system it would be hard to demonstrate how new ideas had any impact. Perhaps creating an optimized system to yield a good baseline is not the most exciting research to focus on but it is a necessity that also exposed students to the true nature of research: one that tends to move slowly with small steps both forward and backward. An interesting observation of this research project is that reaching an optimal baseline took longer than expected as students, though they enjoyed running experiments and learning about speech, did not enjoy the more pain staking process of ensuring

[1] Note that with a relatively new CS major, as the number of graduating seniors rose to about 25% of the entire Capstone project, having all of them focusing on coding made the most sense.

what they did was error free. In its fourth iteration it was discovered that 10% of the data was corrupt due to a past student's script error years earlier. For more than two years (and two full Capstone courses) students struggled improving upon the baseline due to corrupt information yet failed to investigate this thoroughly. It is exactly what one would expect from undergraduate students and though frustrating as a researcher, very rewarding in terms of learnable moments.

What motivated students to immerse themselves into the work was not the research project itself. Though some were excited about the topic, for many, the motivation came from the grading rubric. Only 15% of a student's grade was based on work they had full control over: a set of weekly journal entries. Another 35% came from shared work of a proposal and final report. The remaining 50% came from anonymous student peer evaluations at the end of the semester. These peer evaluations were key in getting students to work given the little guidance or structure. Knowing that any excuse for unproductiveness to the course faculty would fall on deaf ear was a harsh reality for students. Further, each student had to receive a minimum set of evaluations, about a third of the class size, so students had to impact more than a few of their fellow classmates. Being in small groups followed by larger teams allowed plenty of opportunity to do so and at the end of the semester, each student could choose to evaluate as many or as few students as they deemed necessary. The evaluations were done by hand, taking the form of a final exam, where each student would choose which classmates to evaluate, give a performance score and defend that with a few paragraphs of narrative. Students that added little input, missed class time, or just didn't fully participate tended to fail and had to repeat Capstone.

Overall the internal research Capstone project has been a success. Those students who do not pass Capstone either retake it successfully the following year or continue during the summer to complete the work on their own with guidance form the faculty[2]. Many computing graduates speak highly of their experience in Capstone and companies in the area have taken notice. A few companies that hire many of our computing majors are now asking their candidates specifically about their Capstone experience and this is due to previous candidates volunteering the time they had with the project. As it turns out, a challenging and difficult experience, where students have the ability to self-navigate what work they do and how much they accomplish, with the specter of accountability to each other, has had a very positive impact on their final semester in their major and has translated into an excitement that their new employers have felt. Additionally, a better understanding of student ability by faculty working with them on the research project has given the ability to adjust curriculum to fill gaps and improve student outcomes in other coursework. With traditional industry based Capstone, getting this feedback could be difficult at the end of the project. Even with effort to solicit this information through various mechanisms including requests of detailed final reports by those sponsors would yield vague generalizations that were hard to glean insights from.

[2] Being a spring semester course enabled the opportunity to have students finish the work in the summer, those that were only offered to students that received higher than an F but fell below the major requirement of a C- and the best they could achieve was a C-.

To reflect on the characteristics of the Capstone experience summed up in common literature, the undergraduate research experience is a bit different but does share some of the same underlying principles.

- **Project format:** The project is internal by nature and at the discretion of faculties who oversee it and presently focused on speech. It is important that the project has real-world ramifications and thus using a faculty's own research agenda, where the buy-in is their own scholarly work, reflects this clearly back to the students. The project has included an external partner, via collaboration with an ET Capstone project, who wanted the expertise of the group to help build a speech platform.
- **Project content and goal:** A research project generally focuses on both process and results and thus students must develop a rigorous process but are held accountable for results. In the end, an improved set of speech models is sought after as a project goal.
- **Credit hours and accreditation requirement:** The CT Capstone experience at our college comprises 4 credits earned in a one-semester project. However, we also require an additional 4 credits earned for a one-semester Internship experience (i.e. see Case Study 3).
- **Outcome evaluation:** CT shares similar outcomes to ET and includes improved technical skills, collaborative work with others, and good technical communication in both oral and written form. Students come into the project very apprehensive, having heard from past students about the difficulty of the project. The technical topic is challenging, the expectations are high, and with the looming anonymous peer evaluations, students are unable to "hide" from truly doing recognizable work and must find ways to successfully collaborate with their peers. The success of the internal research project has been seen in student and industry feedback where not only students speak highly of their experience but local industry use it in their questioning of prospective candidates.

Case Study 5: A Nascent Internal Faculty Project

Capstone projects that explore research topics new to a faculty member's current research areas can offer distinct benefit to both students and faculty. Students will be exposed to emerging fields of research that allow them to explore independently. They will need to deal with unknowns and to face difficulties while receiving limited guidance, especially compared with students in more established research projects. For faculty, research projects that stem from their nascent interests can help better integrate their teaching and research activities. In particular, these projects provide opportunities to improve pedagogical innovation, such as new directions in the curriculum design of related courses and degree programs [12]. Different from some existing Capstone models that involve broader collaboration between multiple academic disciplines and industrial partners [13], [14], here the focus is on smaller project teams advised by individual faculty members.

Alongside the benefits of these internal research projects, both students and faculty face challenges in the successful completion of such projects. Undergraduate students are usually less prepared compared to graduate students entering a research project. Even though some self-selected students may be very motivated in the topic area, they often lack independent learning and research skills as well as the ability to handle obstacles commonly present in research. In addition, undergraduate students often maintain a regular course load in their senior year and thus left with less time available for the research project than what can be typically expected from graduate students. As Capstone projects are often limited to 1-2 semesters, it is challenging for undergraduate students to produce meaningful contributions and successful results during this short period of time. There might also be a reduction of students' exposure to a wider range of emerging technologies from industry as they engaged in internal research projects.

Meanwhile, faculty advisors in nascent Capstone projects face challenges in creating a satisfying learning experience for the students. A significant time commitment is often required from the faculty advisor to prepare the groundwork in these new topics area as well as to mentor the students who typically have little research experience. In general, undergraduate students tend to have limited foundational knowledge in the discipline even in their senior year, requiring more support throughout the project. In a new research area without an existing project team or graduate students, the support for such Capstone projects often rely solely on the faculty advisor. Moreover, faculty can have additional difficulties in project evaluation and assessment compared to graduate research projects or senior Capstone projects in an established research area.

From experience, several guidelines are adopted to ensure the successful learning outcome from such senior research Capstone projects. First, it is important to clearly define the project scope, while recognizing that such Capstone projects should be structured differently from a typical graduate-level research project. These undergraduate projects should be of reasonable size and in a well-defined topic area. Moreover, the project content should be difficult enough but not overwhelming, involving research activities manageable for students with limited research background and time resources. Second, the faculty advisor should set a sequence of achievable goals to allow students see successful results over time. Students should understand the significance of the new research area and their portion of contribution within the larger project scope. Lastly, faculty advisors working with undergraduate students must commit to a strong mentorship role with frequent meetings and online support. It is also recommended to have an external industrial expert in the new research area be involved in the project. Such a person can produce valuable input in initial goal setting, student's progress monitoring and final project evaluation. Students can thus have more robust Capstone experience and be better exposed to new technologies that are currently used in industry.

As a case study of such internal Capstone project, one faculty member advised a student from another department to complete a two-semester research project on mobile application user experience (UX) testing. No other faculty members within the department have the expertise in the area, while project topic was not directly related to the research interests of the advisor either. However, the faculty advisor agreed to supervise the project given the student's strong interest and excellent academic performance. During the first two months, both the advisor and the student invested a significant amount of time surveying current technologies in UX design and mobile application testing methodologies. After this initial background research, the advisor approved the student's proposal for a new strategy to conduct multi-version cross-platform UX usability testing using a small pool of selected participants. A set of project goals was also detailed in the proposal as research milestones, e.g., strategy design, test validation and evaluation. In addition, the student was required to complete a technical report and disseminate the final results at a professional venue.

Throughout the duration of the project over two semesters, the advisor had regular meetings with the student to monitor his progress. The student was also in contact with a local professional in UX testing to help validate his new testing strategy. The final results of the project were summarized in a research poster presentation in our college's undergraduate research conference and won the first place award in the CS/IT research category. The faculty advisor also integrated some of the research work on UX testing into the current web development and software engineering curriculum. This model allows a broader Capstone experience within the CT program for both IT and CS majors and enables students to choose between a more intensive one-on-one experience with faculty, perhaps lasting two semesters, or be immersed in a research group with many other students in a one semester senior project course.

In terms of the questions identified in the literature review section, the characteristics of the professional experience described in this case study are summarized in the bullet points that follow.

- **Project format:** The projects are assigned by students' interest. Since the projects are internal research projects, industry partners may be optional. Depending on the project scale, the students might work independently or in a team.
- **Project content and goal:** The project is both process and product focused. The goal is to provide undergraduate students an authentic research experience in a topic interested by both the advisor and the student. Students often are required to produce results such as a thesis, poster presentation or a conference publication.
- **Outcome evaluation:** The evaluation of student learning can be clearly evaluated by the research outcome. The project can be formulated with a thesis requirement. Students are required to demonstrate good technical communication in both oral and written form.

Conclusions

In this paper we presented different models for senior professional development work captured in both Capstone projects and Internships. We described several models, covering not only traditional external partnerships with industry but also internal research projects and hybrid approaches to better understand student strength and weaknesses. Computing students experience both internal and external models, as both are required courses in the curriculum. It gives them exposure to industry and still allows faculty to better understand and track their development with the internal research project. Embedding students in companies is important as it not only offers real-world experience but also starts student off on the all-important process of networking, enabling them to be more successful starting their career upon graduation. A lesson learned regarding even successful long-standing external partnerships is that faculty members responsible for Capstone projects need to continue to actively fine tune the collaboration to continue to ensure continued success in the face of changing student needs and interests. As was discussed in the context of Case Study 1, it is vital to work with the external sponsor to choose a scope of work that is achievable within the allotted duration of the Capstone project class. The sponsor needs to be amenable to adjusting the deliverables if the delays are encountered. This flexibility is equally important in internally-hosted projects. Adding the internal element help to better vet students and allowing them to discover what skills they may be lacking as they head into the working world.

Having a mix of Capstone projects in the AES department has given insight into how to improve senior projects for students. The pitfalls of some models are solved by others but each model has its set of strong points and its set of failures. Because CT program majors are subjected to both an external experience, enabling students to spend a semester embedded with a company, and an internal experience, where students work in a large group, collaborating to solve a difficult problem, they leave the program well rounded. Having students immersed in both models also enables faculty to better understand how to modify the curriculum to tailor it to both changing industry needs as well as well as deficiencies in important student skills. An example of this has been the importance of programming skills for IT students. For ET program majors too, though a more traditional model of embedding students with industry partners is used, feedback received from those partners is invaluable in helping to update and upgrade the program.

Students' preparation is an important factor in their Capstone project or research experience. In direct response to student struggles in the internal research project for computing majors, for instance, a path was created that enabled IT students to follow a programming track that not only covered introductory topics but also more advanced ones in data structures and programming languages [15]. Several IT and ET courses incorporate modern software tools and development process so students can adapt to an industrial work setting. Independent learning and problem solving skills have been emphasized throughout the undergraduate curriculum so students are well prepared for a successful culminating experience in their Capstone projects.

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