Issues Associated with Capstone Courses and Growing and Expanding Engineering Technology Programs

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Abstract
Ten years ago, the Electronics Engineering Technology program at Texas A&M University transformed their senior design course into a two-semester capstone design sequence based around a rigorous, real-world product design challenge. The projects undertaken by the students were almost all industry-sponsored and required a large time commitment from the faculty as technical advisors. In addition, the program also embedded entrepreneurship concepts in the course allowing students to use capstone as an avenue for entrepreneurial activities. At the time, enrollment in the course was very steady at approximately fifteen to twenty-five students resulting in approximately four to six teams per semester per course. This was easily manageable by the permanent faculty and resulted in a high quality experience for the students.

Today, ten years later, several initiatives at the College and Department levels have changed the demographics of the program. First, the College has experienced a rapid increase in enrollment over the past five years. This has resulted in entry-level, required program courses seeing an increase in enrollment from 25 to 35 students per course per semester to well over 150 students in the Fall 2018 semester. Even with attrition, it is clear that the capstone courses will have to serve over twenty-five project teams each semester per course in the near future. In addition, the department recently expanded its program offering. A new degree, Multidisciplinary Engineering Technology, or Mechatronics, is now being offered. This degree program uses courses from the electronics program including the capstone course sequence. Thus, the enrollment in the capstone courses will be even larger and will have to contend with student from multiple disciplines.

This paper will discuss these programmatic changes, their impacts on the capstone course sequence and possible solutions. Topics to be covered will include new models for resource constrained, large capstone courses, designing capstone projects to take advantage of multidisciplinary teams, supporting entrepreneurial activities in large capstone courses, and challenges in acquiring external funding for large capstone courses. In addition, the impact on capstone as observed by industry partners will be discussed.

Introduction
Ten years ago, the Electronics Engineering Technology program at Texas A&M University transformed their senior design course into a two-semester capstone design sequence based around a rigorous, real-world product design challenge. The projects undertaken by the students were almost all industry-sponsored and required a large time commitment from the faculty as technical advisors. In addition, the program also embedded entrepreneurship concepts in the course allowing students to use capstone as an avenue for entrepreneurial activities. At the time,
enrollment in the course was very steady at approximately fifteen to twenty-five students resulting in approximately four to six teams per semester per course. With a permanent faculty of ten professors, it was not difficult to find industry or research sponsorship for each team as well as a willing faculty advisor. Thus, capstone was easily manageable and resulted in a high quality experience for the students.

Today, several initiatives at the College and Department levels have changed the demographics of the program. First, the College embarked on what is now known as the 25x25 initiative to grow the enrollment of the College to twenty-five thousand engineering students by 2025. This has resulted in a rapid increase in enrollment over the past five years. A program which originally had an approximate enrollment of 120 students has now grown to over 300 students. This has resulted in entry-level, required program courses seeing an increase in enrollment from 25 to 35 students per course per semester to well over 150 students in the Fall 2018 semester. In addition, the department recently expanded its program offerings. A new degree, Multidisciplinary Engineering Technology (or Mechatronics for short) is now being offered. This degree program uses courses from the electronic systems program including the capstone course sequence and currently has an enrollment of over 150 students. Thus, once these enrollment surges reach the fourth year, the capstone courses will have to serve over twenty-five project teams each semester per course. In addition, the student population will be multidisciplinary, composed of students with a focus in electronics as well as mechatronic systems.

With these rapid changes, several issues now need to urgently be addressed including:

- How to provide oversight for such a large number of teams with limited faculty resources. Currently, the faculty is composed of approximately ten full-time equivalent professors. Under the current capstone model, each faculty member would have to take on the responsibility of advising two to three capstone teams in addition to their official teaching load. This load is not insignificant and under the current model is typically about three to four hours of effort per week per team.

- How to provide funding for each team. Under the current model, the capstone coordinator was tasked with working with industry and faculty researchers to find funding of $10k per project, a reasonable task when there was only four projects per semester. Today, this translates to securing $250k in funding each semester to support capstone.

- How to maintain a quality learning environment. In addition to providing careful oversight for such a large number of teams, facilities must be made available to the students. Several years ago, an investment was made in the “Product Innovation Cellar” or PIC, a 3000 square foot facility with tools, equipment, video conferencing and team work spaces. At the time, the space was designed to support twelve teams in their second capstone semester. Today, needs exceed that space by a factor of two and it is still growing.

- How do we ensure that the capstone experience still meets ABET requirements. The rationale behind the changes to capstone ten years ago was to provide a true capstone experience for all students. With the changes, it is important to ensure we still meet that goal.
This paper will discuss these programmatic changes, their impacts on the capstone course sequence and possible solutions. Topics to be covered will include new models for resource constrained, large capstone courses, designing capstone projects to take advantage of multidisciplinary teams, supporting entrepreneurial activities in large capstone courses, and challenges in acquiring external funding for large capstone courses. In addition, the impact on capstone as observed by industry partners will be discussed.

**Current Capstone Process**

The ESET Capstone Design model which has served the students, industry sponsors and faculty for many years has focused on teams of four students working together as a startup company to transition a sponsor’s problem, need or opportunity into a working prototype in two major semesters (Fall-Spring and Spring-Fall). In addition to the team and external sponsor, the stakeholders also included a faculty advisor who worked as a senior engineer to mentor the students as they designed and developed the prototype. ESET faculty took on this additional academic duty without offloading from their normal teaching requirements.

The experiential learning that resulted from the ESET Capstone model provided each team member a glimpse into the real-world and better prepared them for their entry-level position after graduation. Working on an open-ended project where the team had to work together to design a hardware/software-based solution and then fully implement their design, do appropriate testing and validation, and then document and deliver the solution far exceeds the typical classroom/laboratory learning process. In addition to applying what they have learned in previous classes, the team also learns to use a number of project management tools and processes that they employ in planning their project activities. Unlike other programs that teach project management as a stand-alone course with case studies and hypothetical situations, the ESET Capstone sequence requires all teams to plan their project and then implement and manage the project based on the plan they have created. Having to report weekly on the progress of the project and having each team member show how he/she is meeting the scope, schedule and budget that was part of their planning produces a much richer appreciation of project management and planning.

External sponsorship of most Capstone projects has added significant value to the learning experience of the teams. Concepts, such as “Scope Creep” are best understood when it is real and impacts the level of success a project will achieve. Through the interaction with an external sponsor, the team learns the importance of communications and ensuring all stakeholders are on the same page when it comes to expectations, functional requirements, and performance specifications. In addition to providing interesting and challenging projects, external sponsors also provide funding support for teams to use in developing their prototypes. The faculty advisor has signature authority for the funds that are provided to the University to support the project. The teams must create a reasonable budget in the first course of the sequence and then live to that budget during the second course. These types of real-world project aspects are totally different from the standard course where the student shows up, takes notes, completes homework and exams generally on his/her own and then moves on. It has been said that Capstone is the closest thing to a real-world experience that still includes academic credit.
The external sponsorship is derived from two primary sources: 1) private sector / public sector funding of the projects that they want to have performed, or 2) a faculty research project that generates a Capstone project. An example of the first is the Hermes project. Hermes is a NASA Astromaterials Research and Exploration Science Division project that was taken on by a local startup company, Texas Space Technologies, Applications and Research (T STAR). T STAR is responsible for the design and development of a facility control and communications subsystem that would monitor and control groups of four microgravity experiments that would be conducted on the International Space Station for the next five plus years. T STAR, acting as the overall project manager, sponsored an ESET Capstone team to design and develop the Hermes Facility electronics and software to meet all the functional requirements and performance specifications. As can be seen in Figure 1, the Hermes facility will be installed in a locker and loaded into an express rack space located in the US Lab of the ISS. At varying time intervals, the set of four experiments (Cassette) will be changed out for a new set that will be powered and operated in microgravity. The Capstone team developed a complete system composed of six different embedded intelligence devices (five TIVA4C Microcontrollers and a Beagle Bone Black embedded microcomputer). The Hermes prototype system was demonstrated and delivered to NASA in May 2018 and four flight-qualified systems are now being produced. Based on some recent difficulties with a Russian launch vehicle, the first system has been rescheduled to launch in April of 2019.

![System Architecture](image)

Figure 1. Hermes System Architecture.

**Issues related to Growing Enrollment and Program Expansion**

As previously discussed, with the growth of the program from 120 students to over 300 students and with the addition of a new 150 student program in mechatronics, there is now an overall enrollment of 400 students all sharing the same capstone course sequence. The original capstone course sequence was a very rigorous product development experience that depended on
voluntary faculty advisors, substantial industry and/or research funding, a single faculty overseeing the day-to-day administration of the program. With such rapid growth, the administration quality and advising of the capstone courses are now being impacted negatively. Below are some of the major issues that have been encountered.

Team Size Limitations
To date, capstone team sizes have been kept to a maximum of four students with occasionally three-person groups. The rationale for four team members has been based on ensuring that all team members actively participate in their project. More specifically, the majority of capstone projects involved the development of a functional “intelligent” product involving hardware engineering, software engineering, test engineering and project management. Having each member of the team take the lead on one of these areas ensures that they must each collaborate and participate in order to have a successful design. With the growth in enrollment, larger teams are being considered and trials are being attempted to test the outcomes result from increased team size.

Funding Requirements to Support Prototype Development
Currently, the majority of the ESET capstone projects are funded by either industry or through faculty research. Most projects have a minimum budget of three to five thousand dollars. Thus, most industry-funded projects requested a minimum $10k investment by industry to support the team, the upgrade of equipment and facilities used by the teams, and support of advisor/team activities. With four to six teams, the capstone course instructor was typically able to find funding for all projects. In the future, the requirement of funding all teams will be much more difficult to achieve, requiring a semester budget of 25 x $10k or $250k.

Faculty Advisor Availability
The program has the equivalent of ten, full-time faculty members. With twenty-three courses to administer each semester, it is not possible to assign more than the equivalent of one full-time faculty member to oversee the capstone sequence. While one person is sufficient to administer the courses, the program’s goal is to ensure that each team has a “go-to” faculty member they can consult with when developing their products. For one team, the time commitment for the faculty member is generally about four to five hours per week. When there was a maximum of four to six teams per semester, finding a sufficient number of faculty volunteers to act as technical advisors was a relatively easy task. However, with the increased enrollment, each faculty member would now have to take on two to three teams resulting in an eight to fifteen hour commitment of time over and above their normal faculty load of teaching, research and service.

Adequate Facilities and Resources
Around 2010, the department sought and received funding to create a unique facility to support the capstone sequence. The Product Innovation Cellar or PIC was conceived and built to ensure that teams had adequate resources to support funded product development. Today, the PIC is a reality and offers 3000 square feet of space with a machine shop, a PCB fabrication facility, a computer lab with appropriate CAD software, a conference room, a parts store, and a development area that can support twelve simultaneous four-person teams. At four to six teams
per semester, the facility was more than adequate to support capstone. Today, with the sharp increase in enrollment, the facility will soon exceed its capacity with no ability to expand.

**Ensuring Experiences for Multidisciplinary Teams**

With the addition of the new Multidisciplinary Engineering Technology program, the ESET capstone courses will soon have a diversity of students, 75% with a focus in electronic systems and 25% with a focus in mechatronics. Previously, the vast majority of capstone projects were focused on electronics-based product development. All projects had a microcontroller, a requirement to develop a printed circuit board, and a need for software development. Depending on the project, it was possible that the team needed some minor mechanical engineering expertise, but this was often limited to enclosure design. It is now important that the projects the teams take on have a more significant mechanical component and more importantly, a need for electronics and mechanical system integration. In short, there is an urgent requirement for projects that need multidisciplinary design.

**Meeting University Writing Course Requirements**

A Texas A&M University requirement for graduation is that all students must complete two writing-intensive courses or one writing-intensive and one communication-intensive course prior to graduation. For students in the ESET program, the communication course requirement is satisfied by the first capstone course. In order for a class to qualify as a University-approved communications course, the students must individually complete a certain level of graded written and oral communication assignments. More importantly, the University imposes a maximum student-to-instructor ratio to ensure that all students receive adequate, personalized feedback on their papers and presentations. With fifteen to twenty-five students, this was easily achievable with a single instructor. However, with enrollments of 60 to 100 students in the near future and significant growth to continue, solutions will have to be developed to ensure the course remains certified and the students receive the credit needed for graduation.

With these issues in mind the ESET program has already begun the process of finding solutions to accommodate the growth and changing nature of the students. Most involve developing new mindsets and finding creative ways to address emerging problems. The two sections below discuss some of these new methodologies.

**Lessons Learned**

As enrollment began to increase in the lower-level ESET courses, “what about capstone” concerns began to surface amongst the faculty, especially those that were fully engaged in the process. Because at that time, no teaching credit was available for being a capstone advisor, faculty were appropriately worried about taking on more teams and more projects. A number of ideas on how to handle larger enrollments were generated and the best of these were tested and evaluated to determine the value in supporting larger enrollments in Capstone.

One of the first ideas that was implemented was increasing the number of students on a team from four to six. Four-member teams had been the typical team size for a number of years and worked well in meeting the goal of all students having to work as a team, but all students on the team having a leadership position. By increasing the team size to six provided the ability to absorb a 50 percent increase in Capstone enrollments, but this change comes with a concern
about all team members having a clearly defined leadership role on the team. For some projects that had multiple PCBs to design and/or had multiple software programs to design and implement, having a larger team size provided more engineering manpower which was of value. However, in cases where the project did not include these additional requirements, larger team sizes generally resulted in more conflict within the team, made meeting and interacting harder to arrange due to more individual issues and priorities, and, most importantly, resulted in some team members not having a clear leadership position. Finally, increased team sizes did not improve overall project quality and did not decrease project completion times. Interestingly, when the concept of increasing from four to six students on a team was introduced, the students were vocally against the increase. Several semesters later, a similar negative response came from the Capstone students when the program returned to four-person teams. Larger team sizes can be arranged, but only if requested and justified by the students and agreed to by the faculty advisor and sponsor. All teams during the fall 2018/spring 2019 semesters are four-person teams.

Another idea for handling increased Capstone enrollment was multiple teams working on the same project. Although straightforward conceptually, students were adamantly against this idea whether the teams worked in competition or in complement with each other. Also weighing against adopting this idea was the ability to have external sponsorship of multiple teams. In general, companies did not see the value in funding multiple designs or in breaking the project into multiple teams, each doing a portion of the engineering. Because this idea would not have reduced the number of teams, and because none of the major stakeholders saw value in having multiple teams involved, the idea was shelved without testing.

Almost all departments across the College of Engineering now have Senior Design projects as part of their undergraduate curriculum. The ESET faculty considered an idea that would “farm out” particular students or teams to other programs, departments and colleges. After realizing the significant variation in what is referred to as Senior Design and Capstone projects, the ESET Program also shelved this idea as not meeting the overall goal the program placed on its Capstone experience. Differences in number of semesters, design vs development, level of prototype expected all factored into the decision of the faculty.

Having different Capstone project levels was also an idea that was and is still being considered by the ESET faculty. This idea would allow teams to choose projects based on the level of engineering design required. Some projects would be less rigorous and allow the team to opt out of designing, fabricating and testing their own custom-designed PCB. This aspect of Capstone is time consuming and therefore generates major delays in the team’s prototype development activities as the hardware lead transitions through Alpha, Beta and sometimes, Final versions of the PCB. Each PCB must also be individually populated and tested. This idea would allow teams to potentially choose to lower the team’s highest grade to a B if they bypassed the PCB design aspects of their project and developed the prototype using off-the-shelf development boards and modules. Interfacing these units would require far less time but could still provide the sponsor with a fully functioning prototype. More projects could be conducted, if many of the projects did not require significant time commitments of the faculty advisor and course director necessary to review the schematic capture and board layout presentations that each team
currently conducts. Students have shown interest in the two levels of projects, but are less enthusiastic about having the one-letter grade reduction.

No matter what new processes were considered and put in place, the growth of students and thus the number of teams in the Capstone sequence would place more time demands on ESET faculty to participate as advisors to the projects. To motivate faculty to continue and, in general, increase their involvement in Capstone projects, some form of offloading was necessary. Working with the Department Head, the ESET Program Coordinator was able to provide teaching credit to those faculty who were actively involved. For every two teams that a faculty member advised, that individual would receive loading equivalent to teaching one lab section. The expectation in receiving this teaching load was that the faculty member would become fully engaged in the Capstone team and their project and meet, in a lab-type setting, each week with his/her teams in a much more formalized manner than in previous semesters. Most of the faculty members who were actively involved in advising Capstone teams have stepped up to this new opportunity and have increase their participation in the Capstone process and/or the number of teams they now advise. The quality of advising/mentoring has increased significantly as this new process has been rolled out and more faculty are becoming more interested in participating in the future. However, there are still some faculty who have not found the rewards of being involved with student teams as they apply all they have learned in their undergraduate ESET Program to the design and development of a working prototype to be of interest, even with the new loading model. With future growth of student populations, all faculty will need to be fully engaged in Capstone, if the ESET Program is going to be able to continue this level of experiential education.

Yet another important aspect of sustaining Capstone in the face of significant growth is the availability of good quality projects. The ESET Program has been able to identify five to six new projects per semester for the past five to six years which has been sufficient to meet the program’s needs. However, doubling or tripling this number of projects will not be easily accomplished. Other sources of funding will need to be found to support some of these teams.

One new funding source is currently becoming available. It is based on a unique approach that the ESET Program has taken to new endowments. Rather than having former students and other individuals interested in supporting the program and its students endow scholarships and professorships as is typically done, the ESET Program has encouraged these individuals to set up Capstone Endowments. These endowments then create funding that can be used solely to support the Capstone activities of the ESET Program. Some of these funds will be used to maintain and upgrade the resources of the Product Innovation Cellar which is where Capstone teams design, develop and fabricate the sponsor’s prototypes. The majority of the funds coming from the endowments, however, are earmarked to support Capstone projects. Projects that are generated by the student teams that are interested in developing a prototype with market potential and are serious about commercialization after graduation would have high priority for use of these funds. Projects proposed by tenure-track faculty to support their research interests would also rank high in consideration. To date, three Capstone endowments have been created. As these endowments begin to generate funds, the ESET faculty will be working together to develop the procedures and processes necessary for funds to be allocated by the Program Coordinator.
For all of these new and innovative ideas, the program will need to vet most of them with our private and public-sector representatives. Bringing on representation from other companies that are involved in rapid prototyping, new product development, intellectual property, startup ventures, etc. will be needed to move forward.

Conclusions and Future Efforts
Ten years ago, the ESET program created a rigorous, two-semester, industry and research supported capstone sequence that provided an invaluable experience for all program graduates. This experience was achievable when enrollments required supporting no more than four to six teams per semester. With the rapid increase in enrollment over the past five years and the changing demographics of the students in capstone, the previous model for capstone is no longer sustainable. Issues that the faculty are facing include team size, multidisciplinary teams, shortage of faculty advisors, limitations of project funding, and lack of facilities.

To solve these problems, multiple solutions are being brainstormed and tested. These include new capstone team models, new funding models that rely on endowments, new faculty loading models that give credit to faculty who support capstone design teams. While the problems are not solved, it is clear that a proactive approach is needed to ensure that the quality of the capstone experience is not degraded as the large enrollments start to impact the senior year of the curriculum. As the program moves forward, it is relying heavily on its industry advisory board to help find and provide solutions to the growing problem. With the problem clearly defined, current and new public and private entities that support and benefit from the ESET Capstone experiential learning will be needed to develop a new, sustainable model.

Biographical Information

Joseph A. Morgan has over 20 years of military and industry experience in electronics and communications systems engineering. He joined the Engineering Technology and Industrial Distribution Department in 1989 and has served as the Program Director of the Electronics and Telecommunications Programs and as the Associate Department Head for Operations. He has served as Director of Engineering and Chief Technology Officer in the private sector and currently a partner in a small startup venture. He received his BS degree in electrical engineering (1975) from California State University, Sacramento, and his MS (1980) and DE (1983) degrees in industrial engineering from Texas A&M University. His education and research interests include project management, innovation and entrepreneurship, and embedded product/system development.

Jay R. Porter joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 1998 and is currently the Associate Dean for Engineering at Texas A&M - Galveston. He received the BS degree in electrical engineering (1987), the MS degree in physics (1989), and the Ph.D. in electrical engineering (1993) from Texas A&M University. His areas of interest in research and education include product development, analog/RF electronics, instrumentation, and entrepreneurship.