Integration of Engineering Capstone within a Makerspace Environment

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Abstract

A multi-stage consultative process has been developed within the College of Engineering at New Mexico State University for integration within the college's maker space as a means of promoting technology acceleration and entrepreneurship among capstone projects. The developed process exposes students to advanced resources within the maker space environment by enhancing the capstone experience. This process has broadened student perspectives of capstone projects beyond a purely academic requirement to one that fosters innovation and possibly entrepreneurial opportunities. The developed model utilizes the interdisciplinary environment of a maker space to enhance project quality through an iterative design process, validation, and continuous testing, while introducing students to campus resources for entrepreneurship. As a work-in-progress, this paper will convey the process adopted to identify and guide capstone teams through the engineering design process, discusses preliminary results during the spring academic semester to increase capstone use of the maker space, outcomes to accelerate technology, and planned next steps.

Background

Typical engineering projects within an industry setting require both interdisciplinary and multidisciplinary approachs. However, in a traditional university setting, engineering capstone projects are often completed within a given department with little or no interdisciplinary collaboration. Seaward[1] conveys that, oftentimes, an interdisciplinary approach towards engineering capstones does not occur because of different requirements in engineering departments within a university. Futher, a nationwide survey conducted in 2005 by Wilbarger et al[2], reports that the biggest factor towards the determination of a final grade in a capstone course was the evaluation of the final group deliverable. Thus, understanding department requirements and course deliverables was paramount in the development and adoption of the capstone integrated process.

As a work in progress, the developed process has been focused on increasing the quality of the capstone projects through guided peer mentoring of the engineering design process, introduction to strategies for working effectively in an interdisciplinary environment, and exploring opportunites for technology acceleration and commercialization. In order to ensure alignment with department requirements and course deliverabels, the process has been developed and vetted in collaboration with capstone faculty and college administrators. Once developed, implementation was assigned to a graduate student, whose responsibility was to serve as a liaison between capstone faculty, the maker space, and students enrolled in participating capstone projects.

As capstone teams advance through the semester, they have been guided in the development of prototypes and conduct preliminary testing before vetting/validation of their projects, where they have been encouraged to seek external feedback of their ideas from faculty or "potential clients" of the technology/product being developing. Integration of the maker space within the capstone concept has allowed students to better understand the feasibility of their projects, fosters soft skills (communication, team work, problem solving, critical thinking, etc.), and serves as an initial indicator of opportunities for technology acceleration. The integrated process follows an interative process and strongly encourages prototype testing prior to final project presentation to capstone faculty. Projects that demonstrate commercial application are invited to further accelerate their technology as a client of the university student incubator, where they receive additional commercialization guidance and access to external start-up funding. Thus, the developed integrated process serves to facilitate a shift from a traditional curriculum-driven capstone to one that explores the fringe of entrepreneurship.

College Maker Space

The Aggie Innovation Space (AIS) at New Mexico State University serves as the college's maker space. Operating as a student-managed facility, the AIS provides equipment to assist in additive and basic conventional manufacturing, microcontroller and electronics, and a variety of basic prototyping materials. Examples of some of the equipment include 3D printers, CNC routers, 3D scanners, multiple microcontrollers such as Arduino, Galileo, and Raspberry Pi, and numerous handtools.

In addition, the AIS provides project management and consultation services to engineering students through a peer mentoring model. Engineering students are paired with peer mentors, employed as on-campus Co-Ops, who possess topical expertise in areas such as design, specialized software, and/or programming. A consultation process has been implemented to support projects, regardless of major. The process helps guides student in adoption of the engineering design process, students learn to appreciate the iterative process often associated with technology and product development. Students are encouraged to iterate their projects throughout the semester with periodic check-ins with the maker space staff to ensure high quality and functional prototypes.

The AIS has been operating as a student-managed facility since 2015. Currently, there are twelve undergraduate students and two graduate students employed as on-campus Co-Op employees. The interdisciplinary team of student employees, known as AIS Innovators, are tasked with the technical maintenance, managementl, and day-to-day operations of the facility. An advisory committee, comprised of college adminstrators, faculty, and representatives from the university student incubator, provide fiscal oversight for the AIS and provide guidance on educational programming where applicable.

The AIS Innovators assist students at both the undergraduate and graduate levels. While initially focused on engineering, consultations have evolved to include multidisciplinary projects from engineering, agriculture, art, biology, and business. In the fall of 2015, when the AIS transitioned to a student-run operation, AIS Innovators consulted a total of twenty-seven projects. these projects comprised capstone projects, regular student projects, a few entrepreneurial projects, and projects used for STEM outreach activities. These projects engaged 316 students from varying disciplines. Of these twenty-seven projects, nine were at the capstone level. Table 1 shows a breakdown of the discipline demographics for the capstone projects prior to adoption of the formal maker space integration process.

2015 Capstone Projects	
Department	**Numer of Projects**
Electrical	3
Mechanical-Aerospace	4
Engineering Technology	2
Total	9

Table 1 Breakdown of Capstone Projects during 2015

A total of forty-one students were involved in the respective capstone teams, with AIS Innovators conducting a total of fifty-seven consultations with the purpose of providing technical assistance in the field of design, programming, and prototyping in low and mid-resolution formats. It is important to mention that during this time, the AIS was staffed only by undergraduate students with an academic classification of junior and senior status. The main difference between regular student projects and capstone projects during this time was that capstone students followed a more disciplined process and frequented the AIS more often than students involved in class or personal entrepreneurial projects.

The varied nature of technical assistance, sought by students utilizing the maker space facility led to the development of the discussed Capstone Integration model as a means of addressing the unique nature of capstone projects. Specifically, the developed model focused closely on increasing the quality of capstone projects through increase engagement of services provided with the maker space environment, while maintaining the faculty-capstone relationship.

Consultation Process Developed

Jones et al[3] report in their findings that in a Product Based Learning approach, students that are the most difficult to engage in a project are the ones involved in projects that don't match their career goals. At NMSU, engineering students are given the option to select their top capstone projects and the instructor uses the students' input to assign teams. This is done to ensure that students will be working on a project of their interest and keep acceptable levels of engagement throughout.

The AIS-capstone integration process was developed to keep teams engaged, motivated, and on task in meeting milestones throughout the semester while exposing them to interdisciplinary resources to accelerate their resepetive technologies. A graduate student was hired to serve as a liaison between capstone faculty, the AIS, and capstone teams. Further, the team of AIS Innovators have assumed the role of project facilitators and topical experts with the respective capstone teams. Individualized consultations are provided with each capstone team as needed. As Jones et al[4] states, some students require more guidance from facilitators while others prefer a "hands-off" approach. As such, the AIS Innovators are tasked with identifying an approach that preserves motivation among the team and their project facilitators while balancing the level of assistance provided.

The integrated process was designed to complement the engineering design process. The process enhances teamwork and introduces capstone students to the unique resources within the AIS; i.e. equipment, software, personnel. The ability to establish and achieve key milestones throughout the design process is a major focus of the consultative model. The integrated consultative process is divided into five stages. As students transition across these stages, they are encouraged to establish key short-term milestones and generate project documentation to be used to strengthen their respective project portfolios. Students are mentored on effective ways to validate and justify their decisions to the capstone faculty, project sponsors where applicable, and to their peers.

Stage 0: During this stage, projects are introduced by the capstone faculty and teams are assembled. The AIS has no involvement in the selection of projects nor in the designation of teams for each project. The key milestone for this stage is for individuals to be assigned to a project, meet their clients/mentors, and identify key deliverables and objectives of the assigned project.

<u>Phase 1: Project Onboarding</u>

Stage 1: Teams are introduced to the AIS and AIS Innovators. During this stage, teams undergo an intake consultation. The purpose of the intake consultation is to allow the AIS team and the capstone liaison to become familiar with the project description, purpose, and key deliverables. Ideally, this stage should only last one consultation. In addition to identifying key deliverables, capstone teams become acquainted with the AIS resources and identify opportunities to leverage the resources to advance their respective projects.

The key milestones for this stage is for the teams to become acquainted with the AIS, get introduced to the capstone liaison, and collectively establish project goals and deliverables. By the end of Stage 1, teams receive a refresher on the engineering design process, are provided an overview of the consultation model, and are consulted on specific topics or concepts as a means of getting their projects off the ground. Stage 1 concludes with a brainstorming session to build consensus among the team members on the direction and scope of the project.

Stage 2: Teams meet for follow-up consultations. During Stage 2, the project scope is finalized (Prototype, Research, Proof of Concept, or Process Analysis). Teams are encouraged to communicate with their clients/mentors to ensure the project scope is accepted by all parties (team members, client, and/or mentor). During this stage, the capstone liaison assigns a team of AIS Innovators for each project based on their skill needs and project scope. Key milestones for this stage include a consensus on the project scope and development of a set of initial feasible solutions to be considered.

The objective behind assigning a team of AIS Innovators is to introduce interdisciplinary perspectives to the capstone experience. AIS Innovators provide topical expertise, provide high level brainstorming, provide training on various software, and help train capstone students in safe and proper use of AIS equipment.

As conveyed by Czernikowski[5], it is important to understand that capstone students usually have a demanding academic schedule. And key deliverables and expectations should be realistically stated considering the academic schedules of the average capstone student. Also, faculty members may not have the time to mentor capstone teams appropriately. Thus, the introduction of the AIS capstone liaison serves to complement the capstone faculty as a high-level mentor, who is adept in the engineering design process.

Phase 2: Iterative Design Process

Stage 3: Teams engage in an iterative design process to further refine their projects. Through iterative processes, capstone teams are encouraged to utilize a variety of CAD modeling and programming software, and are introduced to low-resolution prototyping. Building on ideas developed through brainstorming and augmented by decision making matrices, capstone teams then finalize their designs. Throughout Stage 3, the capstone liaison serves to ensure that team designs have undergone a considerable number of iterations to that projects are ready to begin a higher-level prototyping phase.

Stage 3 is intended to focus on iterative processes regardless of the project scope with the primary objective being to strengthen their final designs. At the end of Stage 3, capstone teams should be able to develop a well-tested and designed prototype.

Phase 3: External Validation/Vetting

Stage 4: Developed prototypes undergo validation testing and further refinement of the proof of concept. Ideally, iterations should be minimal at this stage, with most changes being aesthetic. Continuous testing is conducted to ensure that the prototypes are delivering acceptable and working data that can be used to validate the respective design. The validation/vetting phase is intended to ensure the integrity of the project.

The developed model also encourages capstone teams to seek feedback on their respective capstone designs by vetting them before independent sources (non-capstone faculty, community members, business owners, etc.), and where applicable, ensure the project has been designed for smooth transition to the production phase. By vetting their project designs, capstone teams gain additional perspectives on whether they have developed a product that solves a problem.

Continuous testing and product/process improvement are the primary outcomes of the validation/vetting process. Once preliminary testing results yield working data and risk assessments have been conducted, capstone teams then finalize a quote proposal and begin the early phases of a production plan.

Phase 4: Demonstrate, Present and Commercialize (DPC)

Stage 5: Students showcase their projects and present outcomes from following the engineering design process. This final milestone is intended to differentiate between prototype testing and product demonstration. Is an objective that students benefiting from the capstone consultation model will view their capstone project as a possible commercialization opportunity as opposed to simply a requirement for degree completion.

Targeted Capstones

Implementation of the developed capstone integration process officially began in January 2016. The initial targeted capstones involved projects from mechanical and aerospace, industrial, and electrical engineering. The participating departments were selected solely on the on the respective department heads' willingness to help fund a graduate student to serve as liaison between capstone faculty and students. Historically, the majority of the projects that interacted with the AIS came from the department of mechanical and aerospace engineering, largely due to their high student enrollments as compared to other engineering majors, and natural disciplinary alignment with manufacturing and prototype development. This relationship with mechanical and aerospace students provided a natural opportunity to pilot the AIS-capstone partnership. The partnership soon extended to electrical engineering, as students in that department began exploring opportunities to use additive manufacturing to package many of the developed electronic components and sensors within their capstone projects. A partnership with industrial engineering was logical given the shared discipline of additive manufacturing and a shared capstone experience with mechanical and aerospace engineering. It is important to note that industrial engineering students, which as a discipline focuses on processes and systems, helped bridge many of the interdisciplinary collaborations between mechanical and aerospace and electrical engineering projects.

Mechanical and aerospace projects by nature require advanced technical expertise in areas that are often not addressed in-depth in the traditional curricula. As such, the mechanical and aerospace students benefited greatly from assistance in areas such as advanced finite element analysis, which is typically considered to be a complex field of mechanical and aerospace engineering often taught at the graduate level. Additionally, they also benefitted by exposure to an interdisciplinary perspective. This interdisciplinary perspective occurred via engagement with an electrical engineering AIS Innovator with expertise in electronics or microprocessor programming.

Electrical engineering projects, however, required a more defined interdisciplinary approach. A large number of electrical engineering capstones benefitted from the ability to consult with an AIS Innovator with expertise in CAD modeling. Basic as it may seem, the most common need for electrical engineering capstones is in the design of a custom enclosure to house sensors, circuitry, and/or processors. The AIS provided an inviting atmosphere for students to learn interdisciplinary skills that they may not have otherwise been exposed to in their respective current academic curriculums.

Expectations for the targeted capstones was for students to acquire an additional technical skill through engagement in an interdisciplinary environment. AIS Innovators provided technical expertise as peer mentors, thereby allowing capstone teams to learn new skills and advanced technologies that could be applied to their projects. A series of technical interdisciplinary workshops were developed exclusively for capstone students. These workshops consisted of electronics, programming, and soldering workshops oriented for mechanical and aerospace and industrial engineering students, and CAD modeling workshops for EE students. Additionally, generalized workshops were developed for all capstone teams covering common topics such as project management, and use of the 3D printers.

Multidisciplinary Capstones

The capstone projects that have benefited the most from the developed integrated consultative process were from the department of electrical engineering. Several capstone projects from this department are partnered with "clients" from the College of Agriculture, which provides a multidisciplinary approach. Through their use of the AIS, electrical engineering students have embraced the facility's interdisciplinary environement and regularly seek assistance from AIS Innovators. Additionally, the multidisciplinary partnership that these projects enjoy has led to an early realization by the capstone students that resources outside of their academic department were required for an effective outcome.

Specifically, three capstone projects from the electrical engineering department have benefitted greatly from their interaction with the AIS. Two of these projects partnered with departments in the college of agriculture and the other was focused on environmental sustainability. Multidisciplinary projects like aforementioned benefitted greatly from the additional resources available at the AIS, i.e. CAD, prototyping, and user-interface options. These projects also served as an initial indicator that students involved in multidisciplinary projects required additional technical skills outside of their respective academic departments.

Technology Acceleration

In addition to advancing student competency with the engineering design process, the integrative consultation process introduces students to the concept of technology acceleration towards commercialization. Specifically, in the latter stages of the design process, the capstone liaison conducts a technology acceleration inquiry among applicable capstone projects, i.e. projects that support transition to the university student incubator.

Shartrand et al[6] convey that capstone projects present a feasible setting for the implementation of entrepreneurial practices. Additionally, they convey that although engineering students have the tendency of working in established companies, they are also very likely to work in smaller firms and as startup founders upon graduation.

At NMSU, StudioG serves as the student technology incubator whose mission is to help clients identify funding opportunities, introduce them to experienced entrepreneurs, and provides a team of technology commercialization associates to accelerate the commercialization process. StudioG has also expanded their role and has served as the client for capstone projects, particularly those focused on emerging technologies.

Although StudioG accepts projects in various stages of commercialization, the ideal capstone project transitioning to StudioG is expected to have a minimum of a working prototype capable of yielding reliable data and/or results. Thus, capstone projects that have been validated through testing and external feedback within the AIS are given high priority.

Preliminary Results

During the 2016 calendar year, the capstone integration project has effectively consulted a total of twenty-three capstone projects. These numbers show an increase of 256% when compared to the number of capstone projects consulted during the 2015 school year. Table 2 shows a breakdown by engineering discipline of the capstone projects consulted during the 2016 calendar year.

2016 Capstone Projects				
Department	**Spring**	**Summer**	**Fall**	**Total**
MAE-IE	7	3	3	13
EE	2	1	4	7
Engineering Technology	0	0	3	3

Table 2 2016 Capstone Project Breakdown

The increase in capstone consultations is attributed to an increase in student awareness about the AIS and targeted efforts towards integrating capstone projects within the AIS. Targeted efforts included the establishment of a capstone liaison between the AIS and the departments of mechanical and aerospace, industrial, and electrical engineering. While not part of the initial target effort, capstone projects from the department of engineering technology and surveying engineering gravitated to the AIS through organic means such as word of mouth, curiosity in the AIS, and participation in an AIS workshop. The fact that students from other departments are seeking assistance in their capstone projects serves as an indicator of a growing popularity of the services of the AIS including peer consultations conducted by AIS Innovators and the capstone liaison.

Currently, two of the capstone projects that have gone through the consultation process have expressed interest in seeking additional technology acceleration assistance Students from these capstone projects have shown interest in commercializing their technology upon successful and ongoing concept validation.

Success of the AIS model is further evidenced in that, 35% student start-ups in NMSU's StudioG are led by engineering students, making engineering the largest contributor to the campus technology incubator. During the 2015 school year, a total of eighteen engineering projects were accepted for incubation within StudioG. Of these, thirteen engineering start-up ventures have secured over $380,000 in grants, investments, and/or contracts.

Next Steps

One of the major challenges in the capstone integration process lies in the ability to expand the mindset of students involved in capstone projects to include technology commercialization and/or entrepreneurship. Specifically, capstone projects are often viewed purely as degree requirements rather than as commercialization opportunities. Further, students often discard the option of commercializing their technologies because they already have an offer of employment upon completion of their degrees. Future goals of the AIS capstone model will be to engage

StudioG at an earlier stage, schedule visits or team meetings at StudioG, and invite StudioG staff and local entrepreneurs to speak to capstone classes.

Interdisciplinary capstone projects have shown positive results in terms of project quality and team experience. Findings of Wang et al[7] support expansion of interdisciplinary capstone courses, and conclude that invention and entrepreneurship should become a part of the engineering curriculum. As conveyed by Marin et al[8], the optimal capstone is the one that inspires students to take ownership, fosters creative tension, and provides students with the opportunity to fail and succeed. These characteristics can be strengthened through university maker spaces that provide open environments designed for students to find breakthroughs in a learning environment. The AIS takes pride in being such a maker space at NMSU.

Lastly, faculty within the college who also serve on the AIS Advisory Committee will be submitting an IRB request to develop and conduct survey instruments to gauge the impact of the AIS capstone model on student engagement, refinement of critical thinking skills, and willingness/interest in technology acceleration towards commercialization.

Conclusion

By promoting a disciplined yet engaging process, the capstone liaison and team of AIS Innovators have successfully created an interdisciplinary environment within a previously silo-based capstone experience. Additionally, by introducing the concept of technology acceleration and entrepreneurship, the AIS capstone model has provided students with an additional career opportunity following graduation.

By integrating capstone projects with university maker spaces we are intending to enhance the overall student experience through Project Based Learning. All while encouraging students to learn a new technical skills outside of their engineering curriculum. And lastly, by providing an interdisciplinary environment that contributes towards positively towards their soft and entrepreneurship skills.

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