Multidisciplinary Engineering Capstone Design: Successful Implementation at a Regional Hispanic-Serving Institution

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I. Project Background

This paper discusses the creation and first offerings of a multidisciplinary senior design project course sequence at a regional Hispanic-Serving Institution (HSI). The courses, Multidisciplinary Engineering Design I and II (GEEN 4301 and 4302), were created as part of supporting activities for an NSF-STEM grant entitled: "Javelina Engineers STEM Scholarships (JESS): Building the Pathway for Baccalaureate to Masters Degrees," or the JESS Program.

The over-arching JESS Program goal was to identify academically talented undergraduate students across all disciplines offered by the Frank H. Dotterweich College of Engineering (COE) at Texas A&M University-Kingsville (TAMUK) and retain these students through completion of the undergraduate degree. A secondary goal was to increase the number of students pursuing advanced degrees in engineering by providing comprehensive support for both the bachelor's and master's degrees. Students were selected for the JESS scholarship in the freshman to junior year and encouraged to remain at TAMUK through completion of the master's degree. Students taking graduate coursework at TAMUK were eligible for larger scholarships than students taking undergraduate courses. As a Hispanic Serving Institution, TAMUK has a long history of educating and graduating engineers from traditionally under-represented groups. Many TAMUK engineers are first-generation and/or non-traditional college students who face unique challenges. The TAMUK program used a variety of mentoring and career development programs to retain students and encourage them to pursue graduate degrees.

The capstone senior design experience was selected as a major cohort building experience for students in the JESS program since it was a common requirement of most undergraduate majors in the COE. The COE offers seven undergraduate engineering programs, all of which are accredited by the EAC of ABET; one CAC of ABET-accredited computer science program; and one ATMAE-accredited program in industrial management and technology. JESS scholarships were open to students in any COE major.

The COE hosts an annual senior design conference in the spring semester. The senior design conference showcases the work completed in capstone courses in the immediately preceding academic year in a format similar to a professional conference. Senior design teams present for 20 minutes followed by a 10 minute question and answer session by judges and audience members. In addition to current faculty members, many alumni and local industry professionals volunteer to serve as judges. The conference is also open to interested campus and community members. All undergraduate programs in the COE require students to complete a senior design project with the exception of industrial management and technology.

Therefore, creating a senior design course open to all undergraduate majors within the COE was a natural way to improve the cohesiveness of cohorts progressing through the JESS scholarship program. Additionally, the year-long course experience provided a mechanism to deliver career development and mentoring programs, with a special emphasis towards preparing students to apply for graduate school and related opportunities.

II. Course Creation and Implementation

Creating an undergraduate senior design capstone sequence (GEEN 4301 / 4302) that could be taken by any student within the COE provided unique challenges. Majors eligible to participate in the design sequence include the following: architectural engineering; chemical engineering; civil engineering; computer science; electrical engineering; environmental engineering; industrial management and technology; mechanical engineering; and natural gas engineering. Table 1 summarizes senior design requirements and procedures for each discipline.

Table 1. Summary of Senior Design Course Requirements by Program

Program	**# of Courses[1]**	**Credit Hours[1]**	**Prerequisites[2]**	**Additional Notes**
Architectural Engineering	2	4	Environmental Systems for Buildings, Structural Design.	Structural Design course may be selected from steel or concrete.
Chemical Engineering	3	6	Conservation Principles, Heat Transfer Phenomena.	First and second course contain significant instructional content; third course is reserved for design projects.
Civil Engineering	2	4	Structural Analysis, Fluid Mechanics.	
Computer Science	2	4	Senior standing in computer science.	
Electrical Engineering	2	4	Circuits and Electronics Lab, Linear Systems, Microprocessor Systems.	First course is a project laboratory course; second course is reserved for design project.
Environmental Engineering	2	4	Fluid Mechanics, Process Fundamentals, Chemical Principles, Process Fundamentals.	
Industrial Management & Technology	---	---	---	Program uses an employment-preparation course in lieu of capstone design.
Mechanical Engineering	2	4	Machine Design, Design and Simulation.	
Natural Gas Engineering	1	3	6 or fewer NGEN credit hours in future semesters.	

[1] Required for a student to complete the senior design course sequence. One course per semester.
[2] To enter first course in the senior design sequence.

A key element of creating the GEEN 4301 / 4302 course sequence was feedback from the senior design faculty, which proceeded along similar lines as described in [1, 2]. A notable difference between the authors' experiences in [1, 2] and the current project relates to relative program size. TAMUK is a regional institution with a three-year average COE enrollment of nearly 2,700 engineering students and 80+ faculty members. Limited faculty size means that senior design courses tend to be taught by the same faculty members each year. This circumstance made it straightforward to reach out to those faculty most qualified to offer input into the senior design process, without having to select a sub-set of senior design faculty to offer feedback. At TAMUK, senior design faculty worked with the author to prepare the syllabi and course proposals for the GEEN course sequence. The meetings resolved the following issues:

- Selection of appropriate course textbooks, learning objectives, and grading procedures. The success of the annual senior design conference provided a framework for evaluating student performance that offered some consistency throughout senior design courses in the COE, which facilitated these discussions.

- Selection of appropriate prerequisites. After several revisions, prerequisites were adopted to be: (1) senior standing in engineering and (2) permission of department chair. Prerequisite flexibility was necessary to ensure that the GEEN senior design experience continues to meet ABET EAC Criteria 5 requirements to provide "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work" [3]. The faculty and administrative consensus was that maintaining program accreditation is of primary importance for the department chair. The department chair is therefore most likely to scrutinize student eligibility to participate in the GEEN course sequence. A college-wide form was created to document approval by the department chair and dean, as well as to verify completion of the prerequisite course sequence appropriate to the student's major.

- Selection of course replacement per program. Three COE programs focused on the design project in only one senior design course; two of these programs had earlier courses in the senior design sequence that contained valuable information necessary for students' professional success (see Table 1). Therefore, to enhance the usability of the course for all majors, the specific sequence of course substitution was added into the course description for the GEEN courses, as well as reflected on the college-wide form required for students to participate in the GEEN courses. This level of specificity was required to insure buy-in from all departments.

Once the senior design faculty members were satisfied with respect to the intended content and structure of the course, the proposal moved to a series of discussions with the relevant department chairs. Ultimately, the course creation proposal was signed by the chair of each department before moving forward through normal undergraduate curriculum approval channels.

Course creation took approximately 1.5 years to marshal through university processes and take effect. During the life of the S-STEM project, three cohorts of undergraduates engaged in multidisciplinary senior design projects: 2015-2016; 2016-2017; 2017-2018. Only the final

cohort (2017-2018) was able to enroll in GEEN 4301/4302. In 2016-2017, students enrolled in selected topics courses as a stop-gap while the course creation process was underway, and the selected topics courses were substituted for the relevant senior design courses for each student.

In 2015-2016, the first experiment with multidisciplinary senior design was predicated on the supposition that students would benefit from being enrolled in the senior design course sequences appropriate to their majors. Therefore, the students participating in multidisciplinary projects did not enroll in a dedicated class but instead enrolled in the traditional sequences of courses (as shown in Table 1). The 2015-2016 cohort integrated students from multiple majors on an extra-curricular basis; students took on an additional design experience that supplemented their required course or worked with students enrolled in other classes. This effort met with a significant lack of success and became a source of frustration for students and faculty alike. The lack of accountability for work performed in an extracurricular setting plus the different expectations of multiple faculty members demonstrated the need for a dedicated course in future.

While the 2015-2016 cohort faced difficult challenges, the experience gained from this year of projects was valuable. Instructional content was initially developed that would be used in future courses, and methods of monitoring and mentoring student projects were established. The overall quality of the projects themselves demonstrated a sufficient proof-of-concept to encourage the cooperation of the senior design faculty in the course creation process, which was initiated in Spring 2016.

III. Course Content and Delivery

As in any senior design course, a significant portion of class time was spent mentoring student teams, with faculty efforts directed towards value-added instructional content; see also [4], which offers a well-structured approach towards balancing course content. Team-teaching has been demonstrated to be particularly effective for multidisciplinary capstone courses [4, 5]. However, as a regional institution, faculty members at TAMUK carry a high teaching load, which limits the opportunities for truly team-taught classes. All three cohorts of senior design worked primarily with a single faculty member.

In order to provide the perspective that would have been present in a team-taught environment, the senior design instructor enlisted assistance from other faculty members for guest lectures. These guest lectures included overviews of basic project management and advanced three-dimensional drafting techniques. Multidisciplinary senior design students were also encouraged to attend other senior design classes when the topics being presented provided relevant professional development opportunities. Guest lectures by industry professionals and field trips to local companies also played a role in providing experiences in multiple engineering disciplines.

Additionally, faculty members from various departments were engaged in the senior design courses as audience members / guest judges during student presentations, both during students' dress-rehearsals for the COE senior design conference and at mid-year progress report presentations. Each senior design team was encouraged to have a faculty or industry mentor besides the course instructor. By drawing on the experiences of a diverse group of individuals,

the senior design teams were able to form a more complete understanding of the professional issues in their relevant fields and were not limited to the technical knowledge of a single faculty member.

As previously stated, the JESS program proposed mentoring and career development programs to retain students and encourage them to pursue graduate degrees. The senior design course provided a useful delivery mechanism for professional development content. University resources were leveraged to accomplish this objective in many cases, but some industry speakers were also able to contribute. Career development activities included resume writing, interview skills, and professional etiquette. These lectures were frequently open to all students in the JESS program, regardless of enrollment in the senior design course in that semester.

Table 2 summarizes the effects of graduate school recruitment strategies on the senior design cohorts. Of the 40 students participating in the three senior design cohorts, 16 (40%) continued on to graduate school. Undergraduate students in the COE are permitted to register for up to three graduate courses in their senior year. Students in the JESS program who took advantage of this dual-enrollment program were eligible to receive a higher scholarship. Two senior design students completed masters coursework in this way without continuing on to a master's degree at TAMUK or any other institution, for a total of 18 (approximately 45%) of senior design students attempting graduate work at any level.

Table 2. Graduate School Recruitment Summary for Senior Design Cohorts

Team Label	Number of Students	Students Continuing to Graduate School at TAMUK	Student Continuing to Graduate School at Any School	Percentage of Students Continuing to Graduate School
2015-2016				
A	5	2	2	40%
B	4	0	1	25%
C	6	2	3	50%
D	4	0	0	0%
2016-2017				
E	3	0	2	67%
F	3	1	3	100%
G	5	0	0	0%
2017-2018				
H	5	0	2	40%
I	5	0	3	60%
Cohort Totals				
9 teams	40	5	16	40%

Table 2 also demonstrates that only 5 (12.5%) senior design students continued to graduate school at TAMUK. This low graduate school retention rate is disappointing, as an objective of the JESS program was to increase the diversity and quality of graduate students within the COE. However, senior design cohort students who entered masters programs elsewhere were admitted to larger schools with more resources for research and student support, including Stanford and

Cornell Universities. These opportunities should be viewed as an indicator of overall program success.

To accomplish the high level of graduate school recruitment illustrated in Table 2, several strategies were used in the senior design course sequence. A basic overview of national scholarships available for students and how to effectively apply for them was provided by the University's Student Success Office. The senior design instructor provided a more specific follow up about NSF's Graduate Research Fellowship and similar fellowship opportunities. The basics of applying for graduate school and what to expect on the GRE were other topics of discussion.

The importance of peer-mentoring in encouraging under-represented students to consider graduate school has been demonstrated by authors such as [6]. Each senior design cohort benefited from inclusion of peer-mentoring in the senior design courses. A graduate student coordinator was hired through the JESS program to arrange student-led meetings and socials as well as to serve as an unofficial teaching assistant to students working on senior design projects. The graduate student coordinators organized an annual Graduate Student Panel event that was open to all students in the COE. This panel provided the opportunity for students from graduate programs within the COE to share their experiences with undergraduates interested in graduate school. Beginning in Spring 2017, the graduate student coordinator was a member of the 2015-2016 senior design cohort, which provided a close mentoring relationship appreciated by the undergraduate students.

A final emphasis of the senior design course sequence was on professional preparation through improving technical communication and teaming skills. Components of this part of the curriculum followed [7, 8]. Communication skills were refined through several writing assignments and discussions. Particularly successful in advancing the graduate school recruitment objective was a writing assignment that had students critically review and summarize a current research paper in their field.

IV. Design Project Details

A total of nine senior design projects were completed by the three student cohorts. These projects are summarized in Table 3, as are student majors. It should be noted that not all students in the senior design cohorts qualified for the JESS program scholarship. Students in the JESS program were given the opportunity to invite students from other majors to participate in the multidisciplinary senior design class provided those students secured the necessary permission from their department chairs. Of the 40 senior design students, 27.5% were female, 62.5% were Hispanic, and 10% were actively parenting.

Of the 40 students participating in the multidisciplinary senior design experience, 39 remained until project completion. In the 2017-2018 cohort, the GEEN course sequence saw the enrollment of its first student majoring in industrial management and technology (IT). This student elected to participate in only the first semester of the senior design course sequence. Industrial management and technology is the only major in the COE that does not require senior design or participation in the senior design conference. Therefore, the IT student had less

motivation to continue with the project than the remaining students. Moreover, he stated that he felt his major, which focuses largely on the business aspects of technical systems, had not prepared him for the rigor of the senior design experience and did not want to disappoint his group members by not meeting group objectives.

Table 3. Summary of Senior Design Projects

Team Label	Student Majors	Topic
2015-2016 Cohort		
A	Environmental, Electrical, Mechanical, and Chemical Engineering	Automatic Blowdown Control (for local industry)
B	Electrical and Mechanical Engineering	Microcontroller-Based Dual-Axis Solar Tracking System
C	Architectural, Civil, and Mechanical Engineering	Kingsville Event Center with Retractable Roof
D	Chemical Engineering	Unibon Recycle Hydrogen Fuel Gas Injection (for local industry)
2016-2017 Cohort *This cohort worked on three aspects of a central project.*		
E	Architectural Engineering	Javelina Plaza
F	Civil Engineering	Javelina Plaza: Parking Garage
G	Mechanical Engineering	Javelina Plaza: Wind-Turbines
2017-2018 Cohort		
H	Architectural and Civil Engineering; Industrial Management and Technology	Rockport-Fulton ISD FEMA Dome
I	Chemical and Mechanical Engineering	Aquaris: Solar-Powered Water Filtration

Course projects were student-driven, with the exception of a few projects in the 2015-2016 cohort that were requested by local industry. In creating project ideas, students were told to adhere to the following criteria:

- Design something new. Create a product (or structure) that is new and addresses a need.
- As appropriate to the project, create a budget and/or construction plan; include a cost/benefit analysis.
- Use realistic constraints and industry standards.
- Complete advanced calculations and/or simulations to support conclusions.

Both [4] and [9] report using online tools to allow students to join or explore project teams. A similar strategy was adopted in the current work through the use of online discussion boards, but, given the small enrollment in the senior design courses, teams and projects were largely developed through class discussion. Particularly useful was an exercise developed with the 2016-2017 cohort. Students rotated groups for short brainstorming and research sessions, followed by a report out to the class on their project idea. This activity helped break down barriers towards working with students in other majors.

Despite these efforts, however, Table 3 clearly illustrates the tendency for students in the same major to cluster together even though they were in a multidisciplinary setting. This tendency was a significant challenge throughout the JESS program. Four of the nine teams in the senior-design cohorts contained students from only one major, but the 2016-2017 cohort requires additional explanation to be completely understood.

A capstone project for architectural engineering (AE) majors predicates the design of a building, as AE students specialize in the various aspects of building design. AE programs are generally considered multidisciplinary as they encompass structural engineering, electrical engineering, mechanical engineering, and construction management components; as such, teaching senior design courses for this major presents unique challenges [5, 10]. While integrating AE students with students from other majors seems like an ideal way to improve the quality of the overall project, this integration proved problematic because of concerns that other majors would play a supporting role to AE-dominated designs.

Each senior design cohort contained AE students working with civil engineering (CE) students since these majors naturally complement each other in terms of structural engineering and construction management components. However, while mechanical engineering (ME) students could participate in the design of relevant heating, ventilation, and air conditioning systems for a building, concerns were raised by the mechanical engineering faculty that this assignment would not contain sufficient design to qualify as a capstone experience for their students. For this reason, the 2015-2016 AE-CE-ME team decided to add a retractable roof so that their structure had a moving component of greater design interest to the ME students. Similar concerns were raised by electrical engineering faculty that multidisciplinary projects forced their students into a supporting, rather than design, role.

In 2016-2017, the senior design class contained only AE, CE, and ME students. Class project discussions led to the concept of a central project with different aspects being designed by different teams. The Javelina Plaza was designed as a multi-story complex providing entertainment, retail, and study areas for TAMK students. Initially, the design of the Javelina Plaza and its associated parking garage (another campus need) was shared by a team of AE and CE students. These students later diverged into separate teams as it became apparent that there wasn't enough time in a single senior design presentation to do justice to both aspects of the project. The ME student team worked with the AE and CE students to design vertical axis wind turbines to provide a portion of the energy needed to sustain the Javelina Plaza. Therefore, while there were three separate, single-major teams, the entire class actually worked together to present one, unified project concept.

A similar synergy of idea emerged with projects for the 2017-2018 cohort. Both 2017-2018 team projects were inspired by the unusually high number of devastating hurricanes to hit coastal regions at the beginning of the Fall 2017 semester. Several students and their families were personally affected by the storms. One team decided to focus on disaster-preparedness by creating a FEMA-Dome design for nearby Rockport-Fulton ISD (the landfall location of Hurricane Harvey). The other team focused on disaster-response with the design of a solar-powered water-filtration unit for family use. Although the projects were significantly different in scope, the shared motivation improved cohesiveness of the course.

V. Future Work and Recommendations

The multidisciplinary senior design courses offered between 2015 and 2018 were an effective proof-of-concept for the Frank H. Dotterweich COE. Input from senior design faculty from all programs was integrated into the design of the course itself, which improved acceptance of the projects for students wishing to participate. While the JESS project has neared its end, the GEEN courses remain as a useful tool for future multidisciplinary collaboration efforts.

The current project is distinguished from other efforts to create multidisciplinary senior design courses by the small institutional size and the breadth of permitted majors. Rather than focusing on a few, closely aligned majors, the effort at TAMUK has attempted to create a mechanism for all COE students. This breadth has caused some implementation challenges.

Faculty or administrators interested in creating a similar senior-design experience on their campus should consider some of the following lessons learned from the current project:

- Multiple instructors make for stronger multidisciplinary projects. Administrators should carefully consider whether they can devote the faculty resources to make multidisciplinary senior design projects a success.

- Early collaboration builds stronger teams. The tendency of students from a particular major to cluster together was pronounced, but students who shared common courses with other majors were more likely to integrate. An earlier shared course experience had been proposed in the original JESS program, but faculty resources were too limited for it to be implemented.

- Some majors naturally associate on projects. Multidisciplinary engineering projects are intended to reflect "real-world" situations that students will face in industry. The ideal is that co-workers with diverse backgrounds will be asked to collaborate on a project. However, as in the professional world, the senior design teams should reflect the competencies needed to successfully complete the project, which means that some majors will work together more naturally than others.

- Collaboration with non-engineers can be problematic but worthwhile. The current project failed to foster an environment where an IT student felt he could be successful. Continuation of the multidisciplinary senior design course sequence should address this deficiency, perhaps through integration with business students. Students will benefit from learning how to integrate the technical side of engineering with business processes.

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VII. References

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