Know Your Role! Defining Faculty and External Stakeholder Roles in a Multidisciplinary Capstone Course

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Abstract

This paper describes our development of novel faculty roles and our method for the planning and execution of projects in our year-long, multidisciplinary capstone experience. Well-defined roles permit management of increasingly complex multidisciplinary and multidepartment projects, prevent duplication of effort, and help ensure an enriching and rewarding student experience. These roles have enabled us to offer an unprecedented variety and scope of projects with an average of seven students per team from as many as six different majors and four different departments. We discuss difficulties that developed as the course grew and evolved and how the definition of roles and inter-program communication helped mitigate the challenges that arose throughout the process. We suggest that these roles might be incorporated into typical capstone project courses at other universities.

Introduction

The phrase "it takes a village," derived from an old African proverb not only applies to raising children, but also to the selection, assignment, planning, execution and evaluation of projects in a capstone course. However, when contemplating this scenario, another well-known expression comes to mind: "too many cooks spoil the broth." Well-defined roles for faculty and external stakeholders ensure there is suffienct expertise to manage a large portfolio of complex projects, yet everyone involved knows how and when to contribute to provide a truly enriching and rewarding capstone design experience for students.

Capstone Experiences

The capstone experience has long been recognized as a way to incorporate real-world skills desired in the work place with the academic preparation obtained in an undergraduate computer science or engineering program [1]. The capstone experience has also become a means by which to assess ABET outcomes pertaining to working as a member of a team, solving complex problems, and communicating with a wide variety of audiences [2]. Of course, when it comes to conducting the capstone experience, one size does not fit all. A survey of capstone engineering courses found that capstone experiences varied greatly from single quarter to two semester,

real-world problems solicited from industry partners to department-generated problems; from classroom instruction only, to project-only and various combinations thereof [3].

Need for roles to manage increased project complexity

Our capstone experience originally consisted of three separate capstone course sequences, one for each of our department's ABET-accredited majors (computer science, electrical engineering and information technology). Each major provided a separate two-semester sequence to meet this requirement, CS401/402, EE401/402, and IT401/402. This course sequence was mandatory for all seniors.

However, by academic year 2015 it had become difficult to develop project offerings that were realistic, interesting, and of sufficient scope to merit an academic year's effort by a team of undergraduate students, yet only required students from one discipline. The nature of the real-world capstone problems that we solicit from our industry, government and academic partners are inherently interdisciplinary. These external stakeholders pose projects that require the integration of hardware and software and often require expertise from disciplines outside our department. Additionally, until academic year 2020, the ABET Criteria for engineering programs explicitly included in outcome 3d the wording, "an ability to function on multidisciplinary teams" [4]. Capstone projects are our students' primary exposure to multidisciplinary engineering teams. (Note that the current ABET criteria have similar intent, but the wording has been broadened to "inclusive teams" [5].

Through academic year 2015, each course was administered by a course director who managed project selection, student assignment, scheduling and grading. Each project had a faculty member as a technical advisor, but that faculty member received no teaching credit for this work. Therefore, the amount of time the faculty member could devote to capstone advising varied greatly depending on that faculty member's other teaching and research. This resulted in uneven advising of teams, as the faculty member was primarily focused on their assigned teaching and research responsibilities. In academic year 2015, we began the transition to larger and more complex projects, but the existing faculty model was inadequate. For example, one of our robotics teams consisted of eight students: two computer scientists, three electrical engineers, two information technologists, and a systems engineer. The course director noted in the end-of-course report that "the systems engineer on the ground robotics team was poorly integrated. The student was struggling and the advisor could not spare much time for the project as he was teaching a new course and advising other projects." [6]. The course director, with responsibility for course-wide administration and oversight of 16 projects was also unable to provide the necessary time and focus.

Therefore at the end of academic year 2015, to better manage these increasingly large and diverse projects, the discipline-specific course directors proposed several changes that resulted in the formation of XE401/402 from CS, EE, and IT 401/402. The development of the XE401/402 sequence included several changes, including development of a hybrid "agile-waterfall" design process, a focus on reflection within the design process, and these faculty and stakeholder roles. This paper focuses on the implementation of the roles.

Faculty model influences role assignment

The faculty model at West Point includes a relatively large proportion of transient members. Approximately half our faculty consists of military officers who have earned a master's degree and then serve at West Point for a two or three-year assignment. About a quarter of our faculty are more senior officers, serving at the assistant professor level, who have earned a Ph.D. and, like the instructors, are on a two- or three-year assignment to West Point. About a quarter of our faculty members are civilian faculty or permanently-assigned military officers, holding the equivalent of tenure at most institutions, providing the continuity needed for departmental and institutional governance, curriculum development and oversight, and development of long-term research programs. We also have several visiting professors and fellows from other institutions and agencies who remain one to three years and may vary in academic rank from instructor to full professor [7]. While this model provides us with a truly unique and highly-diverse faculty team, the varied levels of education and amount of teaching experience require a faculty allocation model that delineates the teaching load expected in each of the categories.

Due to our complex faculty model with greatly varying educational and experience levels, some faculty categories are more suited to certain roles than others. Codifying specific roles allows us to plan faculty assignments appropriately. It also enables us to fairly allocate teaching credit and helps our students understand the nature of their interaction with the faculty members involved with the capstone experience.

Roles

In this section, we will first introduce and define the roles we established for our capstone experience and then discuss how the faculty in those roles participate throughout the entire capstone cycle. The capstone cycle we employ is shown in Figure 1. The capstone process covers nearly three semesters, with project selection, scoping and student assignment occurring in the spring of a student's junior year and the actual project design and build phases occurring during their senior year.

Course Director

The course director is a senior faculty member who holds the equivalent of tenure at our university. Capstone course directors serve for several years to provide year-to-year continuity. They are responsible for the overall administration of the capstone: creating teams, appointing faculty in other roles, scheduling course-wide events such as sprint and design reviews, creating and refining rubrics and outcome assessment indicators, coordinating with other departments, and selection of projects day judges. As the integrated capstone course evolved from three separate courses serving each program, the course director has come from one of the three program directors. Program director involvement is extremely beneficial, as program directors are very familiar with not only their own but the other programs, the expected competencies of their students, ABET student outcomes, and how the capstone may be used to assess student

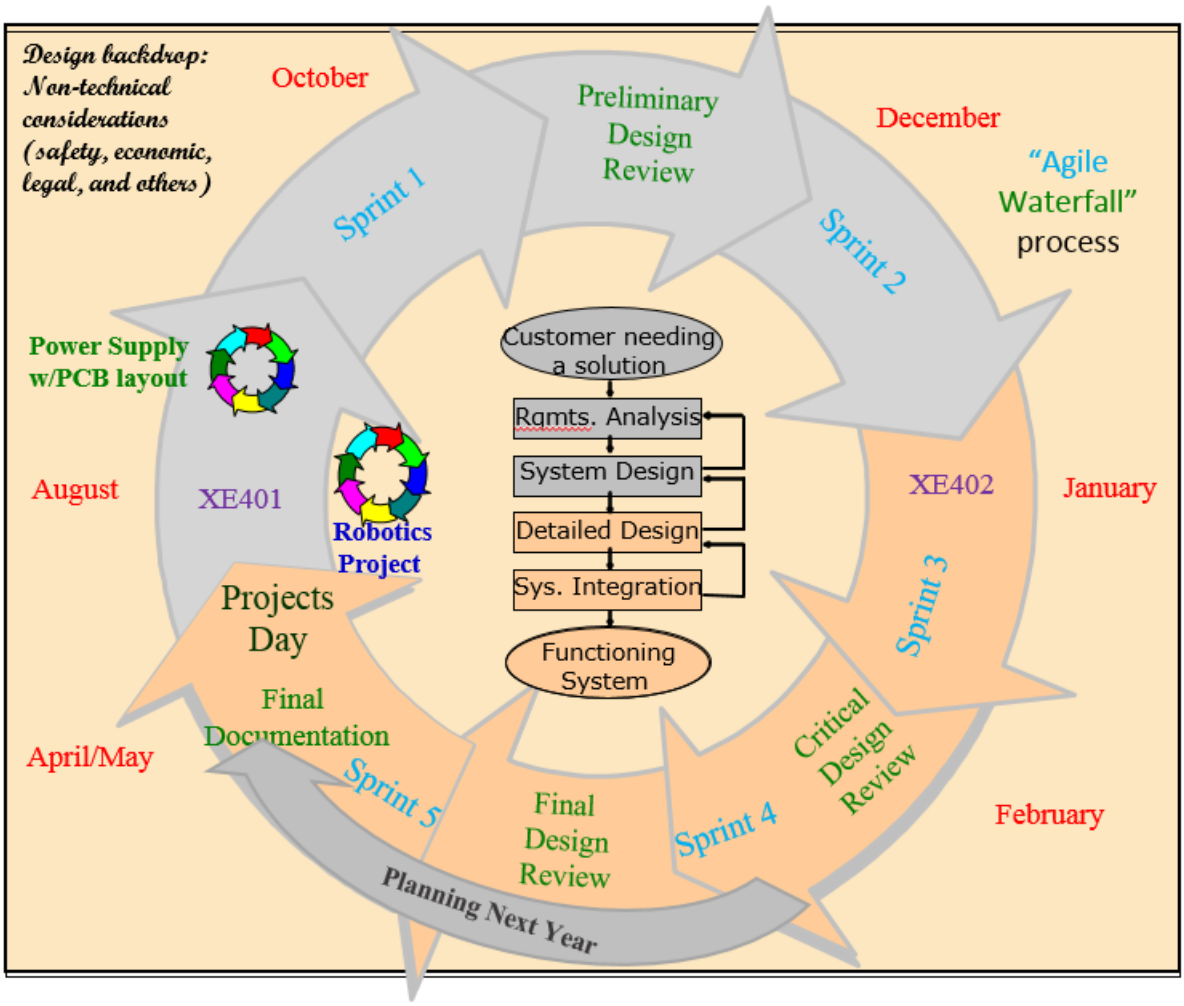

Figure 1: Capstone Cycle

achievement of those outcomes. The course directors who are also program directors are able to integrate assessment into all aspects of the course.

Instructor

Instructor roles are assigned to our PhD-holidng faculty, due to their deep disciplinary expertise as well as teaching experience. Instructors are responsible for grading and mentoring two or three project teams and are given teaching credit for one section of a 3.5 credit-hour course. This is the same credit they would receive for teaching one section of a traditional lecture-plus-lab course. The typical teaching load for Ph.D.-holding faculty is three sections. Instructors serve as the direct interface with students, ensuring they are able to determine appropriate work for a given cycle (or sprint in the Agile lexicon), and helping to remove impediments that arise. Instructors serve as coaches and provide subject matter expertise. Given the complexity of our projects, instructors help students seek out faculty advisors with disciplinary expertise to augment the

instructor's. Instructors administer graded events, perform all grading, and coordinate with the course director in all administrative matters.

Advisor

We continue to have an advisor role, which is assigned to any faculty member with the necessary expertise. Advisors serve as subject matter experts for projects, just as they did before the merger. Advisors are not necessarily assigned to directly support a given team; they may advise several. A team may engage an advisor for a short duration to help with a specific problem, or they may receive support throughout the year. While advisors are not given teaching credit for their assistance, they are gaining insight into the capstone process and dynamics and more junior faculty members serving in the advisor role are often being groomed to take on the instructor role in subsequent years.

Senior Faculty Independent Assessor

Since the teams span multiple disciplines, but the instructor has expertise in one, we added another role to assist with evaluation of the design. The Senior Faculty Independent Assessors are PhD faculty selected to complement the primary discipline of the team's instructor. For example, a team with an instructor whose primary discipline is computer science would be assigned a Senior Faculty Independent Assessor whose educational background is electrical engineering. Ideally, the Senior Faculty Independent Assessor is a full or associate professor permanently assigned to the department. The Senior Faculty Independent Assessors serve on faculty panels for the design and sprint reviews, providing the team feedback from a disinterested but highly experienced viewpoint. The time commitment is minimal, approximately 10 hours in the fall semester and 20 in the spring.

Projects Day Judge

Projects Day Judges provide external, independent assessments of the student projects. Their feedback is critical to assessing course outcomes. The judges are senior executives or engineers from industry or government agencies, or associate or full professors from other academic institutions who have advanced degrees in engineering or computing fields. The eight-member judging team contains representatives of all disciplines in the department. Some members of the judging team are retained from year-to-year to provide continuity, other members are replaced to provide a fresh perspective. Two members have served for over a decade. Some of the judges have an extended association with the department as alumni, former faculty members, or advisory board members. In addition to completing rubrics for ABET Student Outcomes and evaluating projects for departmental awards, judges provide invaluable feedback to the course director and senior faculty. They let us know how our students compare to students at their own institution, others they have evaluated, or junior engineers in their organizations. They provide suggestions on process changes and judges who have come for several years comment on trends. The judges' time commitment is also minimal: one day per year.

Research Center Director

Our department sponsors three research centers: a Cyber Research Center, a Photonics Research Center, and a Robotics Research Center. Each Center has a director and one or more staff members and affiliated faculty. Center directors solicit external stakeholders for projects and, where possible, funding. These external stakeholders then become the customers for the capstone projects. The dialogue between center directors and external customers begins months before the projects are determined. The center director's role of focusing on the next academic year's projects helps to ensure a steady flow of real-world projects. The center director's focus on future years allows the instructors and advisors to concentrate their efforts on the current year's projects.

External Stakeholder

The external stakeholders are representatives of organizations who have agreed to sponsor one or more projects. These are industry, government or other academic organizations with whom we have a pre-existing relationship. For example, we might have a research partnership, or one of our faculty has gone on sabbatical there, or our students have served as interns there. A capstone project may be an extension of a project a student worked on as an intern. The student may have been selected for that summer internship with the specific purpose of leading the corresponding capstone team in the fall. The external stakeholders assist with problem definition and project scoping and are invited to all the design reviews and Projects Day. Some external stakeholders also provide technical assistance or access to specialized resources such as equipment or software belonging to their organization.

Capstone Process with Roles

The capstone course cycle starts in mid-spring, as shown at the bottom of Figure 1, when the course director solicits project ideas for the next academic year from instructors, program directors and center directors. Projects are real-world problems with an actual customer and must be of a scale that may be reasonably accomplished by a team of undergraduate students during an academic year. Over the last decade, the center directors have formed excellent relationships with a significant number of external stakeholders who have consistently agreed to sponsor projects. By the solicitation phase in the spring, the next fall's enrollment is known. The course and center directors negotiate with the external stakeholders to scope the projects based on the fall enrollment. Department faculty also offer projects so that there are more projects offered than we can fill, giving students a choice of projects. Since capstone project instructors are given teaching credit and our faculty find the capstone project experience rewarding, we have not encountered difficulties finding enough faculty to fill the needed roles.

For each offered project, the course director and instructors determine the ideal team composition by academic discipline, including those outside the department. The course director will request students from other departments at this point, so those departments can coordinate our desires

with their own project solicitation. The course director then compiles the projects and provides a list with descriptions to junior-level students in our department. Juniors are then asked to rank order their project preference and also indicate if if there are students with whom they would prefer to work or with whom they would prefer not to work. While student preference is a strong consideration, funded projects must be staffed. The course director then assigns faculty members as instructors for projects that align with the faculty member's academic background and interests. Instructors are assigned two or three projects, depending on team size. Students are assigned to projects toward the end of their junior year, giving them a chance to discuss the capstone projects and process with seniors.

The start of the academic year necessitates course director coordination with external departments to finalize project assignments. The course director may also negotiate scheduling and administration of graded events if students from another department have different requirements than ours. Ideally, all students on a team, regardless of major or department, have the same academic requirements. One way our department has addressed this is to enroll students in our department's capstone course, with an agreement with the student's home department to allow our course to fulfill their capstone requirement.

The fall semester begins with an autonomous ground vehicle (AGV) mini-project. Each capstone teams designs, builds, and tests an autonomous ground vehicle that must negotiate an indoor obstacle course in a limited amount of time. This exercise is meant to build team cohesion and demonstrate the need to use a formal design process. This project ends with a lively competition featuring the success and failure of the various robots, to the delight or dismay of their designers. After the AGV mini-project, students majoring in the computing disciplines and students from other departments attend a series of lectures specifically geared to teach the design process, in our case, a modified version of Scrum [8] [9], an Agile Software Development model, and the classic Waterfall Engineering Design [10] process which we refer to as the "Agile Waterfall" process. This approach allows computing majors to make the most of the Agile approach which champions rapid prototyping and creativity, but also allows engineering students to establish firm requirements and order hardware by set times in order to build and test a working prototype prior to Projects Day. Similar hybrid processes have been employed in which the best of both methodologies are used by teams both in academia and industry [11][12]. Electrical engineers spend this part of the semester learning specific skills needed during the capstone experience, such as printed circuit board design, that were not taught in prior courses. These lessons are taught by the course director and instructors in the capstone course.

After the lesson period, the rest of the academic year is divided into five sprints, two in the fall semester and three in the spring. There are three design reviews that occur in-between some sprints, one in the fall and two in the spring. Instructors serve as Scrum Masters for teams, providing guidance, removing impediments, and serving as the primary communicator with the product owner, who is usually a senior engineer from the sponsoring agency. Instructors also assess student performance for graded events throughout the year. Advisors provide subject matter expertise, as needed, throughout the cycle. Major graded events such as the five sprint reviews and the three design reviews allow instructors to assess each team's ability to properly employ the design process as well as actual progress on their project. Senior Faculty Independent Assessors, advisors, and product owners attend the sprint and design reviews and provide

substantive written and oral feedback as well as input to the overall grade. Since there are several graded events each term, each student is well aware of her or his grade before the end of term. This course is required for graduation with an ABET-accredited major, so students who are in danger of failing are encouraged to get appropriate assistance. In the rare case of failure of either term, the student will either graduate in a subsequent year or graduate with a more general engineering major that has regional (i.e. Middle States) but not ABET accreditation.

The culminating event for capstone students is Projects Day. This is an institution-wide event occurring during the first week of May. Our students participate in a three-hour symposium in a trade-show format. Teams display posters and hardware or software as appropriate to their project and explain their work to an audience that varies from local middle school students to leaders in academia, government and industry, including senior executives from sponsoring agencies. There are usually hundreds of visitors to our Department's venue. Projects Day judges complete rubrics to assess ABET outcomes, select teams for various awards across several categories and provide informal feedback to the course director and department leadership.

Results

Increased faculty buy-in

The delineation of roles has provided several benefits to both students and faculty. Assigning instructors teaching credit has protected faculty time, allowing faculty to devote just as much time to a capstone project as to another course. Prior to the formation of roles, our faculty perceived capstone project advising as a "tax" on their time. The "capstone tax" either placed considerable stress on faculty, or resulted in faculty who were minimally engaged with projects, as mentioned above. Instructors are now able to manage these complex teams, providing both disciplinary and managerial expertise to help the various disciplines work together productively. As an additional benefit, we no longer have any difficulty finding faculty willing to offer projects or fill the instructor roles, whereas in the past it could be challenging to find willing project advisors.

Increased project complexity

Having instructors focus on mentoring pairs of teams has allowed the course director to focus on course-wide oversight. This has allowed our department to offer more complex projects. The percentage of projects requiring coordination among multiple majors and other departments has steadily increased, as shown in Figure 2. Students would be unable to complete challenging multidisciplinary projects without the course director (in cooperation with the center directors) performing the scheduling, resourcing, and administrative coordination that allows us to form teams with members from not only several disciplines, but several departments. The course director has made arrangements with several other departments to allow our course to satisfy their capstone requirement. This coordination among departments is a relationship that requires constant maintenance, due to the transient nature of many of our faculty, as discussed above.

Increased diversity of teams

Another measure of the complexity of the projects is the team composition; we have been able to support a significant increase in the size and diversity of the projects as indicated in Figures 3 and 4.

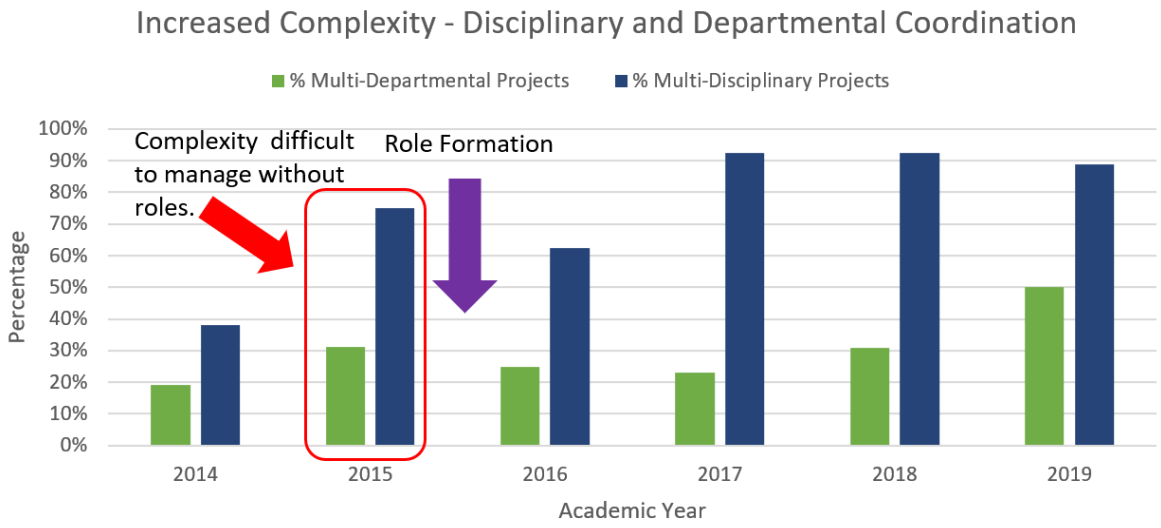

Figure 2: Increase In Complexity: Greater Proportion of Multi-Departmental and Multi-Discplinary Teams

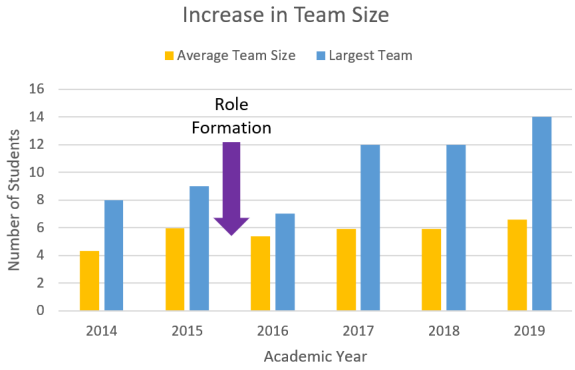

Figure 3: Increase In Size: Greater Average Number of Students and Largest Team Size

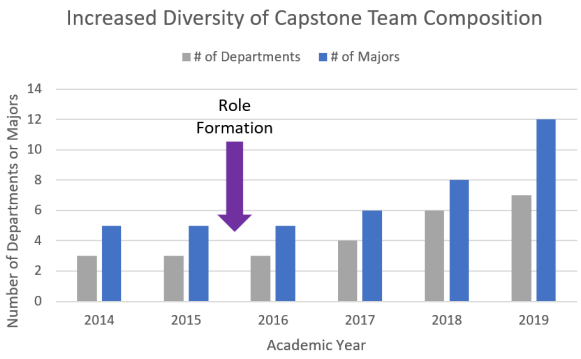

Figure 4: Increase In Diversity: Greater Disciplinary Breadth of Capstone Teams

Team composition has evolved from single-discipline projects several years ago to truly multidisciplinary and multidepartmental projects with students majoring in Civil Engineering, Mechanical Engineering, Systems Engineering, Nuclear Engineering, Environmental Engineering, Geospatial Information Science, Operations Research, and History. Figure 5 shows last year's team composition. Each major arc is a collection of teams overseen by a course director and senior faculty independent assessor. Each minor arc contains two teams with an

instructor and one or more advisors. The dots inside each segment represent students on the team, color-coded by discipline. The faculty names are also color-coded by discipline. There were 13 teams ranging in size from four to 12 students. 12 teams were multidisciplinary and four contained students from multiple departments. The largest project, Swarms, contained students from five disciplines and three different departments. One of the external judges at our annual EECS Projects Day, a former faculty member from the 1980s who served a career in industry after his faculty service and who has extensive involvement with ABET remarked, "The diversity of the teams that I saw when reviewing the capstone project results was amazing. In most projects, multidisciplinary means students from different engineering programs participating on one project team. Here, not only did I see that, but I also saw non-engineering majors participating as full fledged members of teams, including presenting the results. I have never seen this type of discipline integration in a capstone project before." [13]

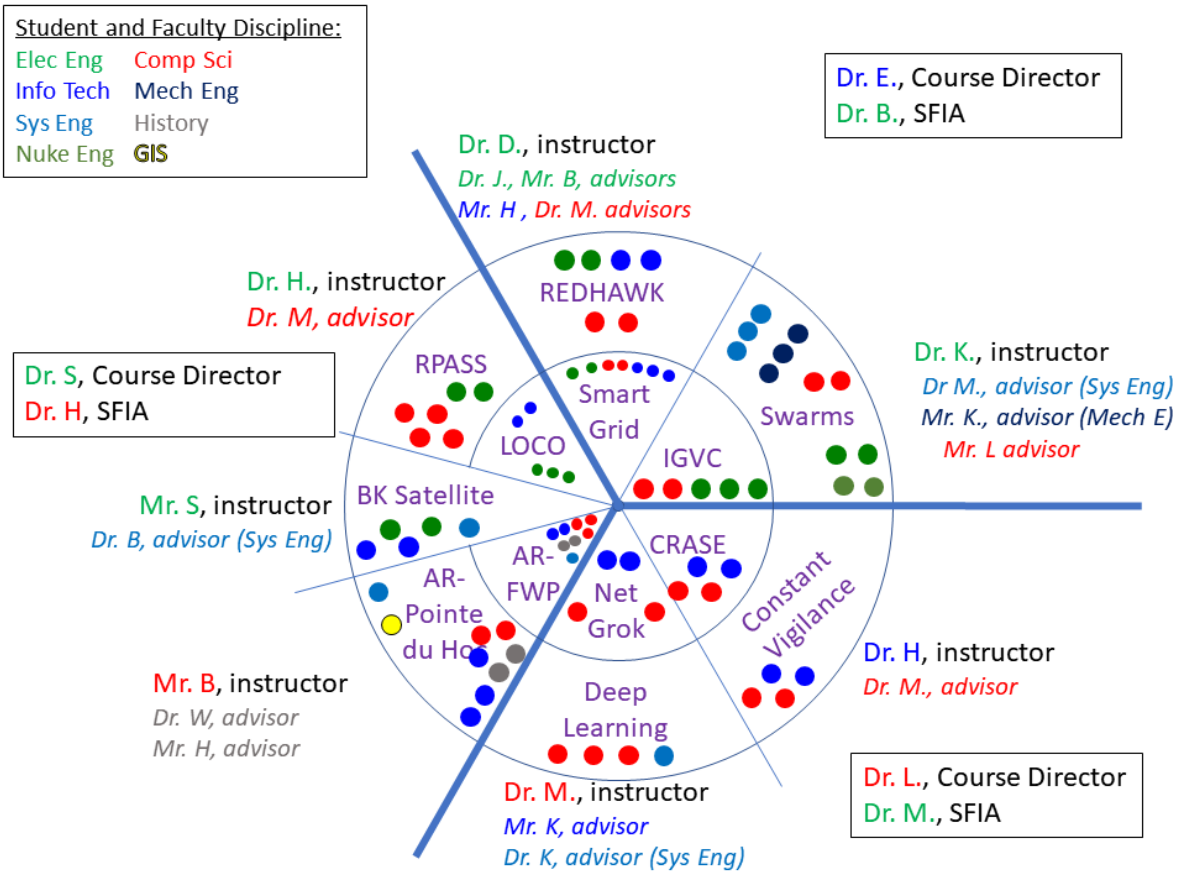

Figure 5: AY18 EECS Capstone Team Composition (faculty and students)

Consistent student performance

Analysis of our student performance over the last few years has shown that our changes have resulted in a slight increase in overall student performance, as indicated by a gradual increase in final capstone course average as well as the total publication count for undergraduates resulting from capstone research, shown in Table 1. The first row, corresponding to Academic year 2015, was before we implemented these changes. The publications listed in Table 1 are all based on the capstone projects, all have undergraduate students as first authors and were all accepted by peer-evaluated conferences or publications. The papers were not required by the capstone project course nor did the students receive a grade or extra credit for writing them. Students invested the additional time and effort out of a sense of satisfaction in their work and a desire to build a resume for post-graduate scholarship and fellowship applications.

Table 1: Capstone GPA and Publication Count by Year

Academic Year	GPA	Publication Count	Comment
2015	3.37	5	prior to roles
2016	3.43	8	after role creation
2017	3.58	3	
2018	3.53	7	

Victory at a National Competition

This year, one of our largest and most diverse teams won the U.S. Department of Energy's 2019 Solar Decathlon competition in the Suburban Single-Family category. This was only the second year West Point had competed. Last year, the team consisted of three Civil Engineers and did not win any awards. This year, the team consisted of a dozen students from six different majors (Civil Engineering, Mechanical Engineering, Electrical Engineering, Systems Engineering, Environmental Engineering and Computer Science) and four different departments (Civil and Mechanical Engineering, Electrical Engineering and Computer Science, Geography and Environmental Engineering and Systems Engineering). The team had an instructor and advisors who represented every academic discipline. The judges commended the DC lighting design and multiple provisions to improve indoor air quality (air quality sensors and monitoring system, a detached garage and low VOC materials). These innovations were due to the diverse team composition that included electrical and environmental engineers and computer scientists. The report was commended for being "easy to read and understand" and the presention was "well done and polished."[14] The systems engineer on the team and the design reviews evaluated by all the advisors helped ensure the quality of the deliverables.

Conclusions

We have found that our delineation of multiple faculty roles within our two-semester multidisciplinary capstone project course has provided significant benefits. We have been able to

increase project realism in terms of project scope, multidisciplinarity, and customer engagement and increase student engagement and depth of understanding while not over-burdening our faculty. While our faculty model is particular to our institution, we believe that our novel diversification of faculty roles could, with some adaptations, be profitably applied by other universities.

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