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Upgrading the Capstone Projects: The Engineering Clinic Model

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Abstract

Capstone engineering design projects are ideal for broad application of engineering concepts on open-ended research and design problems. These projects allow students to reinforce their skills and extend their expertise into specialized areas of interest. Often, the capstone projects serve as both test grounds and launch pads for students' engineering careers. Within the engineering curriculum, these projects typically span the final year of an engineering program and entail a single project within a single disciplinary area. While their significance to the educational experience is unequivocal, the benefits of a capstone project can be expanded to further reflect real-world experiences. Over the span of their careers, professional engineers work on a number of projects and assume a variety of roles within a team of engineers with a range of expertise. How do we model that experience for our students within engineering education? Rowan University's Henry M. Rowan College of Engineering adopted the Engineering Clinic Model (ECM) to replace capstone projects. With ECM students choose to work across traditional disciplinary boundaries on multiple projects over their junior and senior years. The Junior and Senior Engineering Clinics allow students to work on potentially four distinct projects with both juniors and seniors from any engineering discipline supervised by a faculty. The student teams focus on tangible objectives and present their outcomes for each term before moving to another team. The ECM has demonstrated tremendous resilience against enrollment growth and continues to be the most notable aspect of Rowan Engineering. Its resilience can be attributed to an automated process that prioritizes student preferences and faculty interests. The process begins with faculty from every engineering discipline pitching their projects at the start of the term. Students subsequently rank their preferences for those projects. A custom-developed Clinic Match algorithm assigns students to their projects based on a set criteria. The greatest benefit of this approach has been for the students to build desired competencies in a wide range of fields, regardless of the discipline. For the Spring 2019 semester, over 150 distinct projects, representing 5 engineering disciplines, were pitched to over 500 junior and senior engineering students. Students worked in teams typically ranging from 3-8 members on projects; often funded by the government and industry. This paper highlights the key features of engineering clinics within junior and senior years and supports the outcomes with quantitative trends gathered over the past 10 semesters. The Junior and Senior Engineering Clinics offer a powerful alternative for leveraging the capstone design project to impart a broad skill set among engineering graduates.

Keywords: project-based learning, capstone project, student-driven, multidisciplinary, multi-term, design project

1. Introduction and Background

Every engineering program relies on a capstone engineering design project to present a realistic open-ended problem to their students [1]. Students immerse themselves in these projects, typically as team members, to apply their engineering skills and gain "real world" experience before embarking on their careers. Numerous studies have shown the beneficial impacts of these capstone design projects [2]. The ABET accreditation also emphasizes such experiences [1]. The benefits, however, are multiplied when such experiences: (a) are multidisciplinary [3], (b) are extended to multiple terms [4], and (c) are not confined to a single project [5]. This is exactly what Rowan University's Henry Rowan College of Engineering did when it was established. The capstone projects were upgraded and transformed into the Engineering Clinics Model (ECM) [6, 7].

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The ECM spans all four years of the engineering curriculum. The aspects that are analogous to the capstone design project are confined to the Junior and Senior Engineering Clinic sequence. The First-year and Sophomore Engineering Clinics use the problem-based-learning approach to develop the critical engineering skills, namely, the design process and communication. The Junior and Senior Engineering Clinics, is a sequence of four semesters of discrete capstone projects that are selected by the students. At the beginning of each term, engineering faculty propose research and design projects to all the engineering students in the five disciplines at Henry M. Rowan College of Engineering. The five disciplines are: Electrical and Computer Engineering (ECE), Biomedical Engineering (BME), Civil and Environmental Engineering (CEE), Chemical Engineering (ChE), and Mechanical Engineering (ME). The students from these disciplines, in turn, share their preferences for working on a few selected projects. Therefore, students are grouped into teams by their interests and the project needs; not by their class-level (senior or junior) or discipline. Because this process repeats every term, students can choose to work on four distinct projects within or outside their discipline. Each semester this model allows students to work in teams that are multidisciplinary and multi-class-level.

Junior and Senior Engineering Clinics are signature courses at Rowan University. They provide our graduates with a broad practical knowledge of engineering and prepare them for their future careers. When our alumni are asked what they are proud of, Junior and Senior Engineering Clinics are on top of their list. An overview of the ECM and its development has been documented by Kadlowec, et al. [7]. However, the recent success of the Junior and Senior Engineering Clinics is owed to the assignment platform (a.k.a Clinic Match) that priorities student interest and faculty needs [8]. This paper details the assignment methodology and quantitative outcomes from the past 10 semesters of Junior and Senior Engineering Clinics at Rowan University. The implementation and the quantitative trends provide the necessary tools for adoption of the Engineering Clinic Model elsewhere.

2. Methods

Junior and Senior Engineering Clinics begin every semester with a student assignment process that is known as Clinic Match. Once students are assigned to their projects, faculty manage their individual projects and assess the outcomes for grading purposes.

2.1. Clinic Match

Clinic Match is how engineering professors are paired with students for Junior and Senior Engineering Clinic projects. This process is repeated at the beginning of each Fall and Spring term. The process evolved from a paper-based approach and the development of the Clinic Match platform using Google Suite is documented elsewhere [8]. Below are the procedural steps that are followed at the beginning of each semester.

1. Faculty Input. Professors propose their clinic project ideas using a Google Form prior to the start of the term. Faculty specify their student needs with either: (a) the number of students from each engineering discipline, or (b) the total number of students, regardless of their engineering discipline. The faculty also provide project details that include term objectives and engineering skills required to complete the tasks.
2. Student Review. Students have the first three days of the term to review all the project proposals and identify the projects they are most excited about. Students can conference with faculty to learn about specific projects before sharing their choices.
3. Student Input. Students specify their top eight projects using a separate Google Form submission. Students can view a tally of student choices in real-time to guide their selection.
4. The Match. A custom Google Script algorithm assigns students to projects based on a set criteria.
5. Broadcast. The results are shared with faculty and students towards the end of the first week ofclasses.

The Clinic Match algorithm assigns students based on a preset priority criteria. The highest priority goes to a mutual faculty-student interest. Seniors have a higher priority than juniors. Students with experience on the project have priority over new applicants. If all criteria are the same for two students, priority goes to the one that submitted their form earlier. Students are able to view submission tally in real-time to avoid selected popular projects.

2.2. Management, Assessment, and Deliverables

Each project is individually managed and assessed by the faculty lead, who may have multiple projects per semester. A general grading rubric is provided as a guide. Each project is responsible for producing a written report of their project at the end of the term. The team also presents their project in front of other teams and faculty leads in the form of a slide presentation or a poster. A mid-term review is conducted to ensure the teams are making adequate progress towards the term objectives. Teams are expected to practice project management skills as required by their faculty lead. The administration of projects is left to the faculty lead and can vary widely to suit the project needs. At the end of the term, students can decide if they want to remain with the same project or switch to another project. They are encouraged to inform the faculty lead of their plans next term.

3. Results and Discussion

Since the Clinic Match was established in Fall 2014, almost 5000 students have been assigned to 1200 projects. These projects provide a wide variety of experiences, from system design to theoretical research, to our juniors and seniors. While this cumulative number is impressive, the details embedded in the trends of the last 10 semesters are even more revealing. The quantitative trends highlight the scalability of this approach to pair students with faculty that is mutually beneficial. Since Clinic Match was established, two new disciplines were added to the college: Biomedical Engineering and Experiential Engineering Education. These changes were seamlessly integrated with existing platform, expanding project choices for the students and giving student access to newly established faculty in the respective departments.

To appreciate the variety of projects offered each term, Figure 1 presents a pie-chart of the projects proposed by faculty from each of the five disciplines in Fall 2018. A total of 163 projects by 65 faculty were presented to over 600 engineering students in their junior and senior years. That is a little over two projects per faculty on average. The projects were pitched to the students via an online database where students can browse the projects of their interest. This process was repeated every Fall and Spring term. Every term, less than 5% of the projects do not run due to low student interest. These projects are often pitched the following semester.

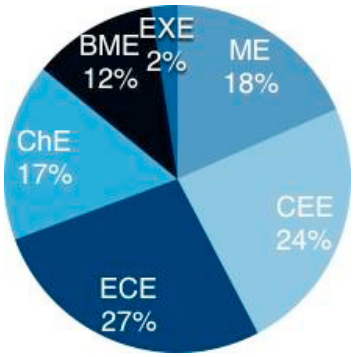

Figure 1. A sample distribution of cross-disciplinary projects offered during Fall 2018. A total of 163 projects were pitched by Mechanical Engineering (ME), Civil and Environmental Engineering (CEE), Electrical and Computer Engineering (ECE), Chemical Engineering (ChE), Biomedical Engineering (BME), and Experiential Engineering (EXE).

The engineering program at Rowan University has experienced tremendous growth in the last five years, not unlike other engineering programs elsewhere. With this enrollment growth, the number of faculty also had to increase. Prior to Fall 2014, the engineering program was relatively small to accommodate an assignment-by-paper process. Post-Fall 2014, Clinic Match has allowed the ECM to scale to meet the growth in enrollment. Figure 2 demonstrates the two-fold growth in enrollment and the subsequent increase in the number of projects offered. Each project team ranged 3-8 members led by an engineering faculty.

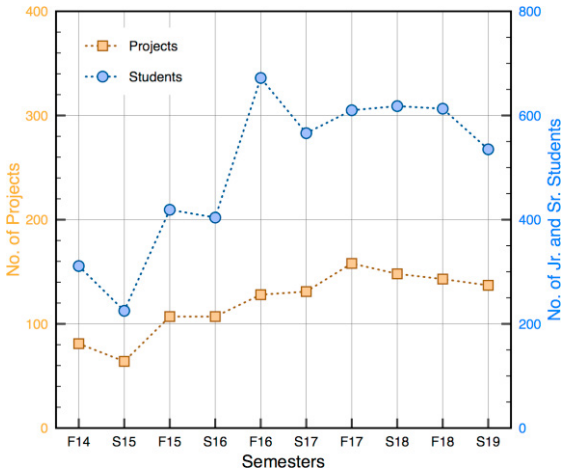

Figure 2. Number of Junior and Senior Engineering Clinic projects proposed by engineering faculty plotted against the number of junior and senior engineering students each Fall and Spring term since Fall 2014.

Considering the projects are accessible across traditional disciplinary boundaries, teams frequently are composed of students from different disciplines. Figure 3 presents the percentage of project teams that can be considered 'multidisciplinary' per term. In other words, teams consisting of at least one student from another discipline. Similarly, teams are composed of juniors and seniors working together. The percentage of these 'multi-year' teams is also plotted in Figure 3. Overall, about 35% of the project teams can be considered multi-disciplinary and around 60% of the teams have juniors working with seniors. These multi-disciplinary and multi-year teams provide a rich learning experience for our graduates. Students with different skills and experiences working towards a common goal is a more realistic representation of their future careers.

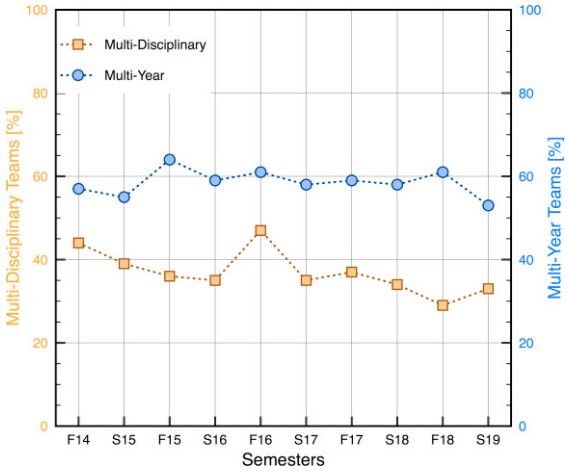

Figure 3. Percentage of clinic project teams that are composed of students from multiple disciplines of engineering compared to the teams with juniors and seniors working together for each Fall and Spring term since Fall 2014.

A typical engineering program involves a single capstone project, often spanning over a single year. The ECM allows students to work on four different clinic projects over the course of two years. Alternatively, students can choose to work on the same project for all four of their semesters depending on their interest. Student autonomy in

designing their developmental path is central to the ECM selection process. To study the variety of projects students choose to work on the class of 2019 was considered. Figure 4 presents the number of distinct projects students typically work on before they graduate. Almost 70% of the students from the class of 2019 had worked on three or more projects. This speaks to the breadth of their experience as they graduate from Henry M. Rowan College of Engineering. Only 6% of the students decided to work on a single project for their last two years of the program. A survey of student motivations for working on multiple versus singular projects can provide useful insights on their career plans.

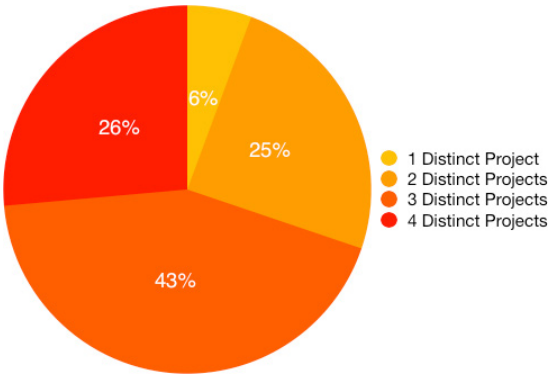

Figure 4. Percent of students who worked on distinct projects for their junior and senior year. Only the engineering class of 2019 was studied for this analysis.

Finally, to provide a better insight on the variety of project experiences, it is often the case that the projects are externally funded by industry or by the government. In these cases, students are accountable to the external partners and frequently interact with these partners directly. This exposure is highly valued and has frequently led to employment opportunities for the students involved. Government sponsored research grants afford funding for graduate students who mentor undergraduate clinic students and can potentially inspire students to pursue a graduate career. Such research experiences prove essential for graduate studies. Figure 5 shows the percentage of projects that are externally funded over the last 10 semesters. Currently, about half of the projects that are proposed, are external funded. The rest are internally funded to support faculty scholarly activities that are valued by the departments.

The forgoing trends support the unique opportunities that ECM offers our graduates. It is expected that the model multiplies the learning outcomes that a typical capstone design project offers. A previous study within the Mechanical Engineering department demonstrated how well ECM is aligned to the ABET outcomes [7]. However, we suspect the outcomes surpass these requirements. Therefore, further investigation into the specifics can shed better light on the unique opportunities the ECM provides for our students. For instance, specific studies can focus on the long term outcomes of working on a variety of projects within a variety of teams. Similarly, what are the effective administration strategies that drive the term's agenda? Is there a set of skills and approaches that make one team more effective than others? Such a study can greatly benefit our program and highlight the program across the engineering education community.

4. Conclusion

The Engineering Clinic Model extends the benefits of a capstone design project by broadening the student experiences. Students are able to work with students and faculty from a wider background and expertise; over multiple terms with multiple projects. The ECM experience is more representative of their future engineering careers than the traditional capstone design projects. The project selection processes is driven more by student interest and less by their class level and discipline. This approach is enabled by the Clinic Match process, that allows a much larger group of students and projects to be successfully paired every semester. These projects drive faculty research, provide students an opportunity to work on industry sponsored projects, and allow students to participate in professional

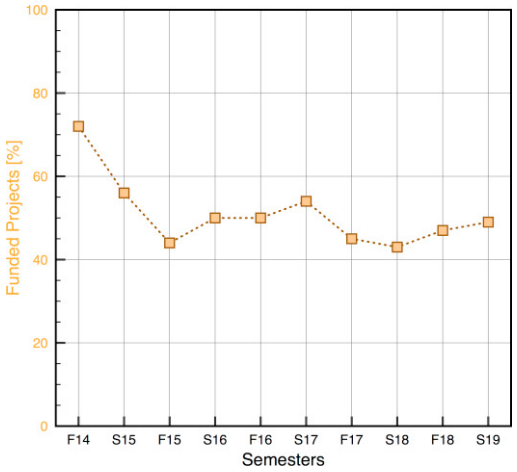

Figure 5. Percentage of projects that were self-reported as externally funded. Funding sources ranged from industry-sponsored to government-sponsored grants.

society competitions. While the educational outcomes of ECM can be easily mapped to the outcomes of a capstone design project, the ECM multiplies these outcomes and provides unique opportunities for that are rarely seen within a traditional capstone design framework. Therefore, the Engineering Clinic Model elevates the capstone design project.

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