

## **Designing Senior Design for Student-Led Projects with Large Enrollments**

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## Abstract

This paper examines the mechanical engineering senior projects ecosystem at the University of California, Irvine, which has one of the top-20 largest mechanical engineering undergraduate programs in the US. We report on the evolution, changes, and future plans of our senior projects experience. In particular, we describe the historical viewpoint of our design ecosystem and why we believe changes were and still are necessary. Next, we present a literature review that provides an overview of best practices in engineering design education. We then describe the changes that we made which are based in part on the literature and our program's needs and limitations, and we present the results of two anonymous surveys of our students. After outlining the specific challenges and opportunities in our program, we describe our plans for future data collection and evaluation of our students. This paper would likely interest colleagues at institutions with large numbers of mechanical engineering students, as well as programs that have various student-initiated projects, team-sizes, and faculty involvement in their project ecosystems.

## Introduction

The department of mechanical and aerospace engineering (MAE) at the University of California, Irvine has relatively unique projects-based experiences within its curriculum. As it is and has been for other universities, our projects *ecosystem* has seen significant evolution due primarily to the following factors:

- Growing enrollments
- Increasing interest in projects from industry, academic leadership, and students
- Faculty needs and interests

By way of a brief history of projects in our department, the beginnings of our senior projects program can be traced back to the early 80s when 50-60 students were first given the opportunity to pursue projects that they defined and managed. These projects existed in parallel with lecture courses on kinematics of mechanisms and design of machine elements. The scope of the projects component grew quickly and by 1990, students were building undersea vehicles that were being tested at Boeing, a human powered airplane, an SAE Baja vehicle, a large dirigible, and more. In 1990, in front of invited reporters, a serious accident with a motor powered hang-glider led the School and University to limit these student-defined and managed projects to a 3'x8' table. At this time, a team of faculty also developed a project course with local companies (MAE188: Engineering Design for Industry). At one point in the mid-90s, all faculty

were required to assist with these industry-sponsored courses, and all students were required to take the course. This approach failed, and it was assumed that forcing involvement was the root cause. While the MAE188 Engineering Design for Industry class remains in existence with 2-4 projects and up to 20 students per quarter, it became an elective.

In 1998, a required, 4 unit Mechanical Engineering Design (MAE151) course with an in-class project for teams or 4-6 students was instituted. By this time there were approximately 100 students in the graduating class, senior project work was still required, and managing every student individually was proving impossible. Therefore project activity returned to being highly decentralized with projects once again being student-defined and managed. The senior design or “capstone” project course became MAE189 Senior Projects, and students were required to take 3 units of MAE189 for graduation. With only 3 “decentralized units,” the ambitions of the students were limited and projects were also, unsurprisingly, of low quality. Around 2005, the unit limit on MAE189 was removed; the 3 unit requirement was maintained, but up to 8 additional MAE189 units could be used for technical elective credit. This was done both to please students who were increasingly finding that project involvement was the easiest way to get an engineering job, and the projects were getting larger, needing students to be active for multiple quarters. In fact, students were starting to get involved in projects prior to their senior year by enrolling in the department’s placeholder-course, MAE195, starting in 2009. It should also be noted that these are all requirements for mechanical engineering students only. MAE189 is not required for aerospace engineering (AE) students, but it can be used for up to 8 AE technical electives. This projects ecosystem is largely in place today and is summarized in Figure 1, and also shows some other courses with design content within the MAE curriculum. Figure 2 shows the types of projects within the ecosystem.

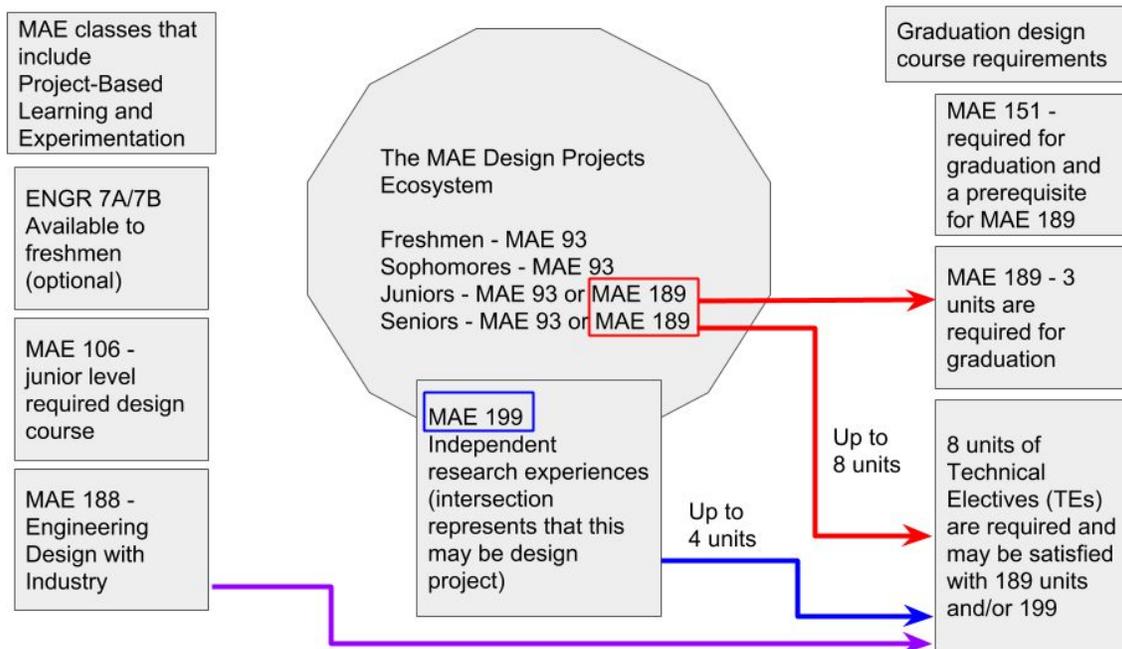


Figure 1: The MAE projects ecosystem showing both in-class hands-on activities/projects and the MAE group projects.

Design Competitions	Faculty Research/Interest	Industry/Product (MAE188)	Student Innovations	Project X / Incubation
Contests providing real-world design experience giving students the opportunity to validate their analytic studies.	Impactful research opportunities funded by the university and other prominent foundations.	Company/individual sponsored projects providing students with opportunities to solve product development challenges.	Opportunities to turn student innovations from concepts to fully fleshed designs.	External sponsors support projects that they are interested in commercializing. .
				

Figure 2: The types of projects in the MAE projects ecosystem.

In 2013, it was obvious that increasing enrollments were impacting the projects ecosystem. As shown in Fig. 3, MAE189 enrollment went from 150 to 300 between 2013 and 2015. Formal MAE projects courses for non-seniors (MAE193/93) were created in AY13-14 and were promoted by advising staff. The immediate impact of these courses is also seen in Fig. 3. The increasing enrollment coincided with institutions and companies realizing that project-based learning was critical to engineering education (Clough, 2005; Atman et al., 2014). It was recognized that our decentralized projects ecosystem needed attention.

MAE 189 and MAE 195/93/193 Enrollment Data, 2009 - 2019

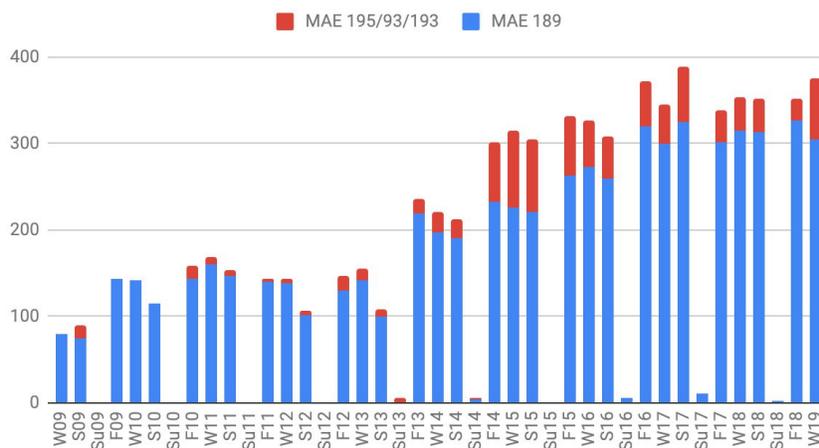


Figure 3: Quarterly MAE189 (senior) and MAE195/93/193 (non-senior) project enrollment data from 2009-2019.

In 2014, a lecturer was hired to bring some structure to the projects ecosystem. This additional structure took the form of an informal progress review, a peer presentation, and participation in quarterly, school-wide design reviews. Documentation templates were generated, but not required to be completed by all project teams. Projects remained student-defined and managed.

Only faculty who were willing and interested guided projects, each having their own requirements and assessment methods. Over the last three academic years, when including non-seniors who enrolled in MAE195/93/193 and students from other departments and sometimes other schools, the projects ecosystem is “entertaining” 350+ students per quarter. Until the fall of 2018, there remained little to no centralized requirements for MAE projects.

In the remaining sections of this paper, we start by exploring best practices in the engineering design education literature. We then describe the changes that have been made to our program and describe the current state of the program. Next, we present results from two feedback surveys which were taken by the students enrolled in the projects ecosystem. In the discussion, we describe our plans for additional changes based on what literature suggests as well as in response to the student concerns. We finish the paper with a plan for future data collection to assess the learning objectives and outcomes in our design projects ecosystem.

## Literature Review

In order to assess the current state of our design program and to confirm that future changes are in line with best practices, we present an overview of literature on engineering design education.

Engineering design education has been the subject of numerous research studies. In 2005, Dym et al. published a paper that examined about 200 articles on engineering design education and determined that teaching and learning design in an engineering context should include having the student be able to do the following: 1) think at the scale of systems, 2) make estimates, 3) conduct experiments, 4) manage ambiguity through convergent-divergent inquiry, 5) make decisions under uncertainty, 6) communicate in diverse languages, and 7) function as part of an interdisciplinary team. Many researchers have explored these seven engineering design experience elements, including developing conception generation skills (Daly et al., 2012), the benefits of model building for dealing with ambiguity (Lemons et al., 2010), and the benefits of reflection practices in learning engineering design (Adams, 2003). Additionally, some researchers have found that design courses should move from an “instructor-transfers-knowledge” model towards a “developing-a-professional-knowledge” model, where students are asked to take charge of their learning and needs (Mann et al, 2007). Crismond and Adams (2012) developed the informed design teaching and learning matrix which outlines specific learning practices between novice and expert designers and also provides suggested teaching approaches. Specifically, Crismond and Adams (2012) define design as:

A goal-directed problem-solving activity (Archer, 1965) that initiates change in human-made things (Jones, 1992), and involves optimizing parameters (Matchett, 1968) and balancing trade-offs (AAAS, 2001) to meet targeted user needs (Gregory, 1966).

This definition of design also connects to many of the elements of engineering design that Dym et al. (2005) specified, emphasizing the complex nature of engineering design that requires

balancing many things at once. With something so complex, experience-based and professional-knowledge oriented design courses can be challenging to assess. In general, engineering design education researchers suggest assessing the students' understanding of the design process as well as their skills in executing the process (Atman et al., 2014). Crismond and Adams (2012) suggest that assessing design can be done through the use of design diaries and portfolios.

Design courses are very often in the senior year of a curriculum, called capstone courses, and frequently in the freshman year, called cornerstone courses (Atman et al., 2014). However, researchers have found that the single capstone and cornerstone model is insufficient. Rather, an integrated and sequential design approach is considered the best practice, where students have design experiences and opportunities throughout their engineering curriculum (Atman et al., 2014). This move toward an integrated model is largely based on emphasizing conceptions of the engineering design process that focus more on what engineers do in practice (e.g. problem framing, resource identification, communication, interdisciplinary interaction) (Atman et al., 2014).

In summary, engineering design education should focus on experiential project-based learning experiences that occur throughout an engineering curriculum, rather than only in Freshman and Senior years as is often the case. These experiences should model what happens in industry, including dealing with ambiguity, uncertainty, and interacting on interdisciplinary teams. Assessment should focus on examining students' understanding and implementation of the engineering design process.

In the next section, we present the current MAE projects ecosystem which includes descriptions of the changes we have made, which were made based on the literature described above, in line with departmental needs and constraints.

## The Current Projects Ecosystem

The courses and projects within our present-day MAE projects ecosystem is still represented by Figures 1 and 2. What is not immediately apparent from these figures is the project management, demographics of the projects, and the assessment of the project work and the individual student work. As described earlier, our institution has a history of student-defined and managed projects. Although a faculty advisor is required for each project, and that advisor is the instructor of record for that particular MAE189/193/93 course, the project management is still left almost exclusively to the students. The student leads manage team member selection, project activity, and budgets; decisions are often made without advisor input. In the current academic year, 2018-19, there are 28 projects, and 11 of these projects are designing and building for national student competitions. Over two-thirds of the 350 students involved in MAE projects are part of these competition teams, and some of these teams have 40+ students, not including volunteers who are not registered for a class. 15 of the remaining projects are aligned with

faculty research, and the last two are student-initiated projects. The instructor of record is responsible for submitting final grades. It is well known that it is difficult to assess design projects, especially in teams (Smith et al., 2005; Dunn-Rankin et al., 1998); There is variability in the methods by which faculty assess the students in their project. There is anecdotal evidence that most of the assessment is not very rigorous.

In summer of 2018, a small task force was created to address the concerns about our MAE projects ecosystem. In particular, there were some success stories, but many students were operating under the radar. In most cases, the hands-off approach to advising led to a poor, inequitable learning environment and many low quality projects. There was strong anecdotal evidence that many students were taking advantage of the ecosystem for a GPA boost and resume padding. The overarching goal of the task force was to implement changes that would a) raise student involvement in design process, b) improve student and project quality, c) encourage students to do more engineering and less crafting, and d) assess each student enrolled. Any changes needed to be done in such a way as to work for all the different types of projects, to be possible with 300+ students, and to not burden project advisors. In other words, centralized requirements were needed, and our effort to implement them is described next.

Starting in Fall 2018, the students and teams were required to participate in the activities shown in Table 1, which details the individual and team-based activities and whether these activities contribute to learning about or practicing the design process, analytical skills, teaming, or communication skills. The most notable change was requiring all students to attend weekly check-in meetings. In addition, students were told that they could only enroll in one project per quarter. The team activities were not new, but there was a commitment to grade all items centrally and pass the grades on to advisors. For individuals, peer evaluation had been implemented in AY17-18, but the weekly check-in sessions and notebook submission were completely new. The check-in sessions consisted of ten students each with one instructor or TA and took place six of the ten weeks in Fall 2019. Students were required to submit a single powerpoint slide with the following information:

- 1) What were the requirements you addressed this week?
- 2) What were the tasks you completed that addressed the requirements?
- 3) What is the evidence you have for completing your tasks? (include pictures and diagrams)
- 4) What are the tasks/requirements you will address next week?

Each check-in session lasted 50 minutes, providing each student with five minutes to present their work and answer questions. The instructional team wanted each check-in session to have a variety of projects represented so that students could learn to present to a range of audiences, including students who are unfamiliar with their project details and also to learn about and from other project activities. 29 of 39 check-in sessions were led by 1 full- and 2 half-TAs which were 20 and 10 hours per week, respectively. The remaining sessions were divided up by 3 faculty

members. Grading of documentation (see Appendix for an outline of the required project documentation that spans 3 quarters of project activity) was shared by TAs and instructors.

Table 1: Individual and Team Activities for MAE Projects

Individual Activities	Grade	Design Process	Analytical Skills	Teaming	Communication
Weekly Check-Ins	30%	X	X		X
Lab Notebook	10%	X	X		X
Peer and Course Evaluations	10%			X	

Team Activities	Grade	Design Process	Analytical Skills	Teaming	Communication
Schedule and Overarching Goals	5%	X			X
Progress Reviews	3%	X			
Website and Roster	2%				X
Participation in Design Reviews	5%	X	X	X	X
Documentation	30%	X	X	X	X
Peer Presentations	5%	X	X	X	X

## Student Feedback to Changes

In response to the changes that were implemented in Fall 2018, a number of students formed a “discord” group to voice concerns. In part, some students felt that we were “ruining” their project experience. The main complaints were as follows: too much time to prepare for and participate in check-ins, inconsistent grading, incompatible structure for some projects, each team member needing to have weekly tasks, too much emphasis on presentation versus technical support, and loss of freedom to participate in multiple projects. In order to capture responses from everyone in the course, rather than only the select few who contacted us directly, we conducted an anonymous mid-quarter feedback survey. The questions and student responses are presented in Table 2.

Table 2: Mid-Quarter Anonymous Feedback - 283 Responses

Question	Disagree	Tent to Disagree	Tend to Agree	Agree
I believe it is beneficial to contribute to my project on a weekly basis.	3%	2%	3%	82%
I feel that presenting my work in the check-in meetings will	17%	19%	35%	28%

help me prepare for future job interviews.				
I feel that presenting my work in the check-in meetings will help me prepare for my future work in engineering industry and/or graduate school.	17%	16%	36%	30%
I understand what is expected of me in the check-in meeting.	10%	14%	31%	45%
I feel that use of the check-in grading rubric is helping me understand where to improve my presentation content and skills for an engineering job and/or graduate school.	22%	22%	34%	22%
I feel prepared to discuss my contributions in the check in meeting.	6%	10%	30%	54%
I feel that preparing for the check-in meeting encourages interaction with my own team members.	34%	22%	25%	19%
I feel the check-in meeting encourages interaction with those on other projects.	25%	26%	29%	20%
I feel that it is beneficial to learn about my classmates' project work through the check-in format	27%	20%	35%	18%
I feel that the engineering design notebook is a useful way for me to of keeping track of my design contributions and thoughts.	17%	15%	32%	35%
I feel that the increased accountability and structural changes to senior projects have been positive.	25%	24%	35%	16%

In general, it seems that the majority of student respondents agreed or tended to agree with the survey statements. In particular, most students agreed that it was important to contribute to their projects on a weekly basis (85%), felt that they were prepared to discuss their contributions during the check-in meetings (86%), and also felt that they knew what was expected of them in the check-in meetings (76%). Most students agreed that the check-in meetings would be useful in preparing for future jobs (66%), and fewer students thought it would help them prepare for interviews (53%). Even fewer students agreed that the check-in meetings encouraged interaction with people on other projects (49%).

Two additional open-ended questions were asked: 1) "Do you have any comments on your responses to the above questions?" And 2) "Do you have any suggestions for how the MAE Design Projects Program individual assessment experience can be improved? Please keep in mind that as this is an educational experience that counts towards your graduation requirements, we need to provide an equitable experience to all students. In your response, please make sure to include suggestions for any changes you wish to see in the future." 197 of 283 students gave a response to question 1 and 200 of 283 students gave a response to question 2. Students responded to both questions with comments about program issues and suggestions.

Students' suggestions for program improvement included numerous complaints. Students wanted more consistency across their check-in instructors' grading approaches; they wanted the ability to keep an electronic notebook rather than a hard-copy notebook; they wanted fewer or no check-in meetings; they wanted their check-in sessions to be project-based rather than across projects; and they were concerned that preparing for and sitting in an hour-long check-in meeting was too time-consuming, especially for students who were only taking one unit. Additionally, there were a lot of complaints about how the changes to the class were implemented, and that there was a lack of communication about the expectations associated with the changes.

Some responses were not about the check-in meetings, but dealt with other aspects of the project requirements. In response to question 2, numerous students commented on the tediousness and misalignment of our documentation assignments, which are the team assignments shown in Table 1, with the tasks they need to do for their competitions. Some students view the design documentation assignments as being in conflict with their design work. Furthermore, through the nature of the competition projects, teams would like to submit work from previous years.

After the mid-quarter feedback survey, we also offered to hold a focus-group meeting so that interested students could speak with the instructional team directly. Four students attended the focus group meeting, and reiterated many of the complaints and concerns identified in the survey. The two major issues that were discussed at the focus group were: 1) the students wanted a way to communicate more openly with the instructional staff and suggested Piazza as a platform, and 2) the students wanted more interaction with their faculty project advisors.

At the end of the quarter, we again conducted an anonymous survey, however, this survey had more of a focus on the project teams and sought to identify if students were satisfied with their team leadership and advisor involvement. The questions and student responses to the survey are presented in Table 3.

Table 3: End-of-Quarter Anonymous Feedback - 213 Responses

Question	Disagree	Tent to Disagree	Tend to Agree	Agree
I am clear on my team's goals.	0%	1%	15%	84%
My team leader ensures that the team remains on course as it works to accomplish its goals.	1%	1%	23%	74%
I feel that my team works hard to achieve its mission and goals.	1%	1%	26%	72%
I have a personal ownership towards my team's mission and goals.	0%	2%	25%	73%

I am applying the knowledge I have gained from my previous coursework to my project work.	2%	6%	28%	64%
My team has an open communication structure that allows all members to participate.	1%	2%	21%	76%
My team's faculty advisor / instructor cares about our project and our success.	4%	7%	20%	70%
My check-in session instructor provided useful feedback on my check-in slides.	11%	15%	36%	39%
The weekly check-in sessions helped me stay on track with my project work this quarter.	27%	23%	30%	20%

Question	Much Less	Less	The Same	More	Much More
My team would like to meet [less, the same, more] with our faculty advisor.	2%	4%	57%	32%	5%

In general, the students who responded to the survey agreed with positive statements about their team goals and dedication to the team and project. While most students agreed or tended to agree (90%) that their team's faculty advisor cared about their project and their success, many (37%) wanted to meet with their faculty advisor more in future terms. Finally, in response to the two questions about the check-in meetings, students generally agreed that their check-in instructors gave them useful feedback (75%). However, only 50% of students agreed that the check-in sessions helped them stay on track during the quarter.

One open-ended question was asked: "Anything else you would like to share?" 125 of 213 students responded to this open-ended question. In these open-ended responses, students remarked on many of the same issues that were identified in the mid-quarter survey. However, there were also numerous students who commented on the check-in sessions being valuable. For example, one student said:

"Although MAE 189 had a rough start this quarter with all the changes, I think the overall vision is there and that progress has been made. Despite the initial uproar, many students are aware that changes like these take time. Overhauling a major part of the department is no small task. I greatly appreciate all of the staffs efforts in improving the program."

Another student suggested that project leads have a separate check-in session, since they mostly conducted project management tasks and could then "talk to each other about our projects and learn from each other about how we are all running our individual project." Other students commented on the check-in sessions and documentation expectations being time-consuming and stressful. For instance, one student on a competition team reiterated that they do not have time for the course documentation requirements, since the competition also

had documents due. However, for some students, they realized that both the presentation and documentation requirements were beneficial to them. For example: “Mae 189 has been more stressful than anticipated, but I am aware it is important to learn how to do these presentations and documentations.”

Numerous students commented on the fact that the check-in sessions scheduling was a challenging aspect of the changes, and suggested that the schedule and sign-up for check-ins be done sooner in future quarters. Additionally, students described concerns about taking a small number of units with the increased requirements. Many students commented on their perceptions of the presentation requirements and course requirements being unclear, and being inconsistent from week to week.

## Discussion

It is clear from the previous sections that our projects ecosystem has a history of being highly decentralized. The original design projects curriculum subscribed to the idea that faculty had imparted the students with all the knowledge they could, and it was time to let the student exercise their knowledge and creativity. Additional justifications for the decentralized approach over the years include ideas and notions that a) students learn best when they are responsible for their own decisions and mistakes, b) ownership leads to better outcomes, and c) faculty are too busy (and not sufficiently incentivized) to individually mentor the large numbers of students in projects. In our case, the decentralized nature of our projects ecosystem became part of the culture within MAE. Many of the disadvantages of a decentralized projects ecosystem have been outlined in previous sections. In particular, there is clearly observed non-uniform learning experience, poor assessment of student work, poor project quality, and non-negligible numbers of students who do not contribute. Of increasing concern are issues of diversity and inclusiveness that can run rampant in a decentralized system such as ours, especially as students initiate, form, and manage their own teams.

One of the unique aspects of our for-credit projects ecosystem is the fact that more than two-thirds of the students are involved in competition projects. The currently active student competition projects are listed in the appendix. Competition projects present unique challenges within a capstone design program. The projects themselves are very demanding for students who have a large number and variety of commitments outside of their project work. Timelines challenge even the most organized students. The competition-required documents are not always aligned with design course documentation requirements. As is the case at UCI, the excitement of competition leads to large teams with ambitious goals, but in the end, only a small number of students are dedicated to seeing the project through. Costs are extreme both in real dollars and in time, and dedicated fundraising is needed but rarely supported. It can be difficult to integrate students from other disciplines such as communications, business, etc., into what is, at its heart, a for-credit engineering course. The focus on winning takes away from the required intellectual growth and assessment of individual students mandated by a for-credit, ABET-approved course.

Just as there is no such thing as a perfect design, there is also no such thing as a perfect design projects program. Specific design project programs in the literature are not easily translated across institutions. However, literature does tell us what learning outcomes to focus on. The findings from literature and specific departmental needs and constraints were the basis for the changes, described earlier, that we made to the program starting in Fall 2018. We plan to continue to iterate in order to meet and enhance the following design projects course objectives for our students:

- Develop a full understanding and demonstration of the engineering design process
- Integrate course knowledge and analytical skills into the engineering design process
- Develop and use teaming skills
- Employ professional communication skills

In the short term, we plan to no longer require students enrolled in MAE193/93 to sign up for check-in sessions and have instead asked that project advisors oversee these students' work and contributions. This change will be implemented in order to start to differentiate between students working towards graduation requirements rather than students who simply want to be involved in a project, which is mostly freshmen, sophomores, some juniors, and some seniors who have completed their 189 requirements. By focusing our increased assessment on students earning credit for graduation, we feel that our requirements would be more aligned with expectations for graduating seniors. We will request that project advisors require their 189 students to take at least 2 units so that the requirements associated with check-in sessions are not as much of a significant portion of their weekly time. We will also be asking advisors to be more involved with documentation by approving documentation submission schedules and any requests for extensions. Notebook submission will transition to a pdf upload of a digital lab notebook and/or scanned pages from handwritten notes. For full credit, the notebook pages must show weekly engineering or management activities. The leads and other students engaging in few or no technical activities will be split off to managers check-ins where weekly check-in assignments will be aimed at teaching project management skills. Finally, we will also start using Piazza as a communication platform to make announcements about the class and to encourage inter-project discussions about resources and common issues.

In the intermediate term, we will have begun teaching MAE151 Mechanical Engineering Design, which is the required 4-unit mechanical engineering senior design course, each quarter, thus allowing it to become a prerequisite for MAE189. In parallel, we will explore ways to ensure that each student is contributing to required engineering documentation. In the long term we would seek to develop MAE93 into a kind of projects apprenticeship program. This class would become a "design-spine" for our curriculum (Gallois & Sheppard, 1999), providing design experience throughout the curriculum, where the activity would gradually change from hands-on tinkering, to manufacturing training, to guided assembly and testing, to shadowing more senior students. This apprenticeship model would allow for students of all levels to be involved in design projects in a formal way throughout their curriculum. Students "graduating" from the apprentice program would be ready to begin meaningful MAE189 *engineering* design work and

to mentor younger students. A centralized core of instructors and staff would keep this projects apprenticeship program on track.

## Future Pedagogical Assessment

The main question motivating this work is: How can we give our students the best project design experience that will help them become better and more productive engineers?

To this end, we will continue to iterate on the design of our MAE Projects Ecosystem. In particular, we plan on evaluating the learning outcomes of our students to determine how they are performing on the seven elements in engineering design contexts outlined by Dym et al. (2005). These seven elements are as follows: 1) thinking at the scale of systems, 2) making estimates, 3) conducting experiments, 4) managing ambiguity through convergent-divergent inquiry, 5) decision-making under uncertainty, 6) communicating in diverse languages, and 7) functioning as part of an interdisciplinary team.

We will continue to collect feedback surveys from our students to see what their reactions and perceptions are. While having students achieve desired learning outcomes is our primary goal, we are interested in making adjustments that address specific student concerns that still align with the learning goals.

Finally, we are interested in learning how other schools are running their design programs. In our original plan for this current paper, we wanted to conduct a benchmarking exercise to see how similar mechanical engineering programs ran their senior design experiences. However, we found that publicly available information on websites was not sufficient for gathering the information we needed. For example, it is difficult to understand the background and specific goals of a program or experience based on descriptions offered online. In order to better understand how other similar institutions implement their senior design experiences, as well as how they handle competition-based projects on their campuses, we plan on surveying and interviewing the 30 institutions that graduate the most students with mechanical engineering bachelor's degrees (Yoder, 2017).

## Conclusions

In this paper, we outlined the design projects ecosystem at the University of California, Irvine, a large, R1 institution in the Southwestern United States. Our program is ranked in the top-20 for most number of mechanical engineering bachelor's degrees awarded in 2017. With increasing enrollment in our program, a number of changes in our design ecosystem were implemented and subsequently assessed in comparison to literature on engineering design education and based on student feedback.

Some of our biggest challenges associated with our design projects are associated with managing a diverse set of projects in a decentralized ecosystem. Many of the projects our students are involved in are competition-based, putting into question many of the overarching course structure we have attempted to implement. In future work, we aim to better be able to answer the following question: How can we give our students the best project design experience that will help them become better and more productive engineers?

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# Appendix

## Design Project Documentation

### **1. Team Formation and Contract**

- 1.1. Introduction
- 1.2. Team Name
- 1.3. Team Goal
- 1.4. Organizational (Org) Chart
- 1.5. Identify Support Structure and Available Resources
- 1.6. Team Communication Plan
- 1.7. Team Contract
- 1.8. Signatures

### **2. Project Discovery**

- 2.1. Background (external driving factors and context)
- 2.2. Problem Statement (clarify the need)
- 2.3. Updated Project Goal Statement
- 2.4. Requirements (measurable)
- 2.5. Generation of Engineering Concepts (delivering things that meet requirements)
- 2.6. Analysis (calculations, simulations, project risks)
- 2.7. Testing (mini-experiments)
- 2.8. Concept Review/Selection
- 2.9. Final Design Specification

### **3. Project Design for Safety**

- 3.1. Safety Concerns
- 3.2. Breakdown of Design Concepts
- 3.3. Preliminary List of Training Requirements
- 3.4. Summary

### **4. Product Specifications**

- 4.1. System Breakdown (into assemblies and components)
- 4.2. Project Schedule (tasks, objectives, milestones)
- 4.3. Design Drawings (assemblies and components)
- 4.4. Analysis (verification of requirements and design review)
- 4.5. Generate the Bill of Materials (BOM)
- 4.6. Manufacturing Plan (make or buy)

### **5. Realization: Manufacturing and Assembly**

- 5.1. Health and Safety
- 5.2. Cost Analysis and Purchasing Plan
- 5.3. Fabrication/Assembly and Verification
- 5.4. Tooling, Assembly Fixture, and Test Apparatus Fabrication
- 5.5. Failure Modes and Effects Analysis
- 5.6. Selective Component Testing Plans

5.7. Requirements Update and Drawing Revisions

**6. Project Safety Plan**

- 6.1. List of Hazardous Materials Involved
- 6.2. Equipment and Experimental Apparatus
- 6.3. Personal Protective Equipment (PPE)
- 6.4. Training Requirements
- 6.5. Member Training
- 6.6. Operational Procedures
- 6.7. Public Safety

**7. Project Testing and Validation**

- 7.1. Testing Approach
- 7.2. Resource Requirements
- 7.3. Test Environment
- 7.4. Test Responsibilities
- 7.5. Test Details
- 7.6. Test Results
- 7.7. Validation Summary

**8. Project Closure**

- 8.1. Description
- 8.2. Scope Statement
- 8.3. Accomplishments
- 8.4. Financial Summary
- 8.5. Inventory and Records
- 8.6. Lessons Learned and Recommendations
- 8.7. Team Lead(s) Comments
- 8.8. Appendix A: Team Members

## Student Competition Projects within our Projects Ecosystem

- <https://www.sae.org/attend/student-events/>
  - Baja SAE
  - Formula SAE
  - Formula SAE Electric
  - SAE Aero Design
- <http://americansolarchallenge.org/the-competition/american-solar-challenge-2018/>
- <https://www.spacex.com/hyperloop>
- <http://www.cansatcompetition.com/>
- <http://www.igvc.org/>
- <http://base11spacechallenge.org/>
- <http://www.auvsi-suas.org/competitions/2019/>
- <https://www.aiaadbf.org/>