Using a Systems Engineering-based Approach to Run a Large Project-based Program: Lessons Learned Over 12 Years of Education

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Abstract

At Iowa State University, we have been running an innovative program that allows students, from freshmen to senior students, to be engaged in hands-on learning using a Project Based Learning framework with a flipped classroom approach. While the aerospace engineering department runs this program, it is open to all students and involves a diverse and multidisciplinary group of students. Many lessons have been learned over the last twelve years of running this program. This paper reviews the lessons learned, what changes we have made to the program, and a discussion on continuing adaptations to the program to continue the program over the next ten or more years.

One of the most significant challenges with a program like this is how assessment can be done in a fair and unbiased manner. We will discuss how we have adjusted our grading rubrics and approaches over the years, especially as the program grew from around eight projects and fifty students to, at its peak, two hundred and eighty students and sixteen projects. Over the years, we have learned which assessments have effectively evaluated the students while balancing the workload on students and the instructors and teaching assistants involved in the program.

Another challenge with a project like this is managing a diverse student group and managing the projects to keep students on track and ensure that deliverables are met while doing this in an academic setting. These challenges, along with the variety of student projects, create unique management situations as some projects are tied to competitions while others are working with a client. We will discuss approaches we have taken to help manage the projects and the systems engineering approach we took to resolve these issues. This approach also gave us a unique opportunity to teach our engineering students these skills, skills that are only sometimes covered in other courses.

Finally, we will present the program's impact on our students. We have collected student comments and feedback that have shown the positive impact the program has had. We also continue to get feedback from our alumni and industrial affiliates involved in the program. We will show these impacts and how we continue to use this feedback to continuously improve the program.

Introduction

The purpose of this paper is to provide a detailed account of the Make to Innovate program's history. We wanted to explain why we adopted our specific strategy and pedagogy approaches. Our program has been operational for many years, and over this time, we have continuously adjusted it to cater to the needs of students and meet our objectives.

We implemented the Make to Innovate program to provide students with practical, hands-on learning. This approach helps students develop critical thinking skills, promotes creativity and innovation, and prepares them for real-world challenges. To achieve these goals, we adopted a strategy that focuses on project-based learning. This approach encourages students to work collaboratively, learn from each other, and tackle real-world problems.

Our pedagogy approach is centered around the idea of learning by doing. We encourage students to experiment with different materials, tools, and techniques to develop their skills. Our instructors act as facilitators and guides, providing students with the necessary resources, support, and feedback to help them achieve their goals.

Over the years, we have continuously evaluated the program's effectiveness and made changes to improve it. We have added new projects, updated our curriculum, and incorporated new technologies to enhance the learning experience. We aim to ensure the program remains relevant, engaging, and meaningful to students.

Background information

The Make to Innovate (M:2:I) program began in the fall of 2011. The program aims to provide students with hands-on experience in solving real-world problems. The Make to Innovate program launched with around ninety students working on fifteen projects. The program aimed to include projects operating independently in the aerospace engineering department and provide a more structured environment for the students working on those projects. It also helped to facilitate additional resources that could be earmarked for said projects. As seen in Figure 1, enrollment has grown and fallen. The program experienced its peak in 2017, with over 280 students enrolled. This partially aligned with record enrollment at Iowa State University. The other reason for the increase was better program promotion in different departments. COVID-19 and a decline in the university's overall enrollment have contributed to the decline. As the program matured, we began balancing the number of students on each team, capping teams at six members and averaging three teams per project. We also added a pre-requisite for the freshmen engineering 101 course to be taken first. The main reason for this was to have students who had at least one semester of college and had at least some very basics of engineering before jumping into this program. This resulted in a program that was more stable in enrollment numbers.

Along with changes in student enrollment, the number of projects managed by the program has also changed. At the program's inception, there were twelve projects, which peaked at twenty-one. However, in recent years, we have focused more on hosting quality projects with clear objectives and goals. This reduction has resulted in managing fewer projects and enrolling fewer students. However, it has also ensured better allocation of resources, ultimately leading to a higher quality of the learning experience.

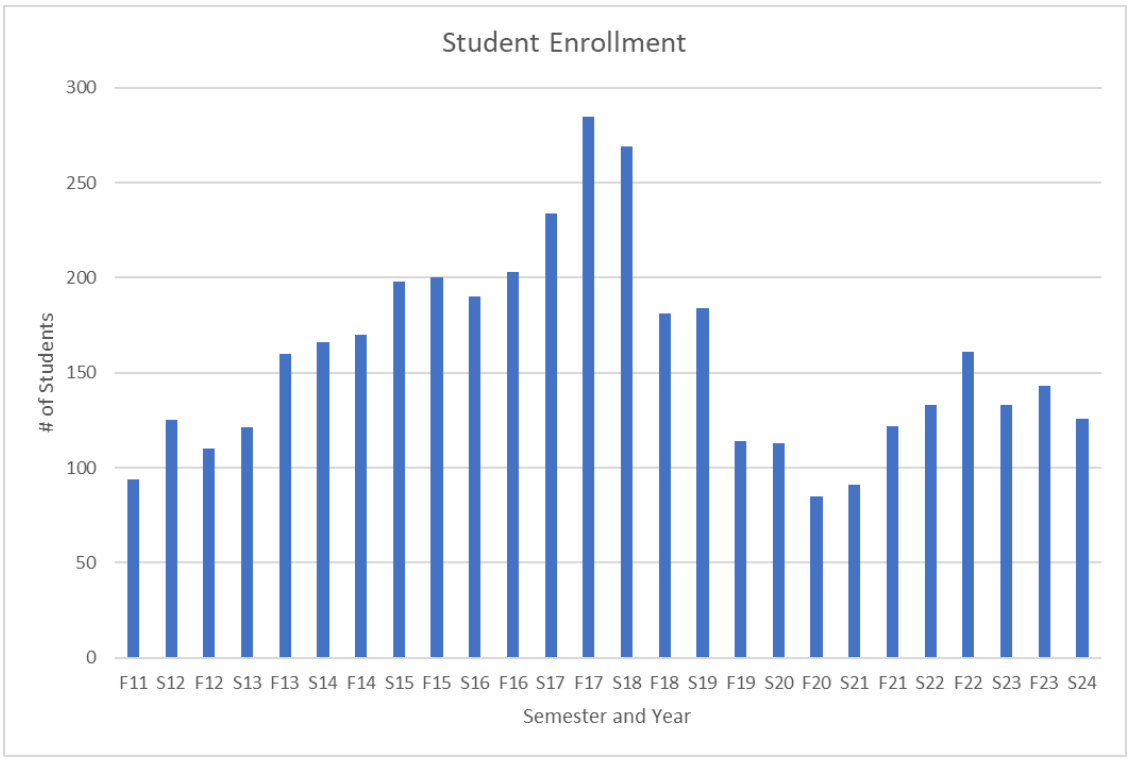

Figure 1: Student enrollment since 2011.

The course is designed to uniquely teach various skills, including engineering, project management, and professional skills. The course uses a flipped-classroom approach, meaning there is no assigned class time. Instead, each project arranges weekly team meetings and work times to complete the tasks. A student leadership team is established for each project to ensure smooth operations. That team runs the weekly meetings and serves as points of contact for the project. Finally, the program has a unique approach to assessing success. It evaluates whether the students achieved their goals, learned new skills, and improved their existing skills.

Our Make to Innovate program offers two courses: a one-credit sophomore-level course (AerE 294) for first- and second-year students and a two- or three-credit senior-level course (AerE 494) for juniors and seniors. Students in leadership roles must enroll for three credits, while all other students enroll for two. We use the general rule of thumb that for every credit hour, we expect students are work around 2-3 hours per week.

Enrollment in the program has consisted mainly of Aerospace Engineers, with approximately 70-80% of the students enrolled from the Aerospace Engineering Department. This prevalence can be attributed to two factors. Firstly, the program is administered by the Aerospace Engineering Department. Secondly, Aerospace Engineering students can allocate up to six credits towards their technical elective, while other departments may not accept as many or any at all.

The rest of the student makeup comprises Electrical, Computer, and Mechanical engineering students. The program is open to all majors on campus, and enrollment has included students

outside of the engineering discipline, including Meteorology, Biology, and Design. These students provide additional diversity to the program and bring additional skills that are often needed in many of the projects in the program. While many projects are rooted in engineering, many competition-based projects require skills outside of engineering.

One challenge we have had is with the perception of the program from students outside of the Aerospace Engineering department. In a perfect scenario, we would have more students from different disciplines based on the project's needs. So why does this not happen? Two factors come into play. The first is course credit. Students in Aerospace Engineering may apply up to six credits to their degree as a technical elective. For Aerospace Engineering students, this happens reasonably automatically. Mechanical Engineering students, on the other hand, must fill out a form, which must then be approved. However, up to six credits can be applied to their degree. Electrical, Computer, and Software Engineering can only use three credits. It has been challenging to get these often very much-needed students into the program or to stay for more than one or two semesters. The second reason is that students usually do not understand the importance of participating in interdisciplinary projects [1] or feel as though they may not have anything to contribute. In reality, students gain valuable skills, and diversity in the different disciplines allows the projects to be more successful in achieving their goals.

Pedagogical Approach

Make to Innovate began with no real framework, and initially, the program was run as one large independent study course. This led to several issues, with the largest concern being that students were not learning anything with the program. Assessment in the program's early days was also not well-defined, resulting in the program's reputation for being an "easy A" course. It was clear that a better framework and assessment plan was needed for the program to be successful.

To achieve our objectives, Make to Innovate employed an innovative and dynamic approach to teaching. We implemented a Project-Based Learning (PBL) framework, a learner-centered educational method emphasizing hands-on, real-world problem-solving. In addition, we utilized a flipped classroom model, which involves reversing the traditional teacher-centered classroom dynamic so that students are at the center of the learning experience. With this approach, students have more agency in the learning process.

Using hands-on learning frameworks like PBL (Problem-Based Learning) is a concept that has been introduced previously [2]. Other institutions have used PBL for engineering and non-engineering courses [3]. Ongoing research into PBL suggests that the classroom implementation level varies [4]. In the Make to Innovate course, PBL is a critical component of the learning environment, and we have designed the course to focus on this learning technique. We divide all work into projects, placing the project teams responsible for completing their goals. Students learn new skills and apply current skills to real-world problems through continuous assessment and advising throughout the semester.

To execute this strategy, we adopt a flipped classroom model that centers around the students and shares information informally. Flipped classrooms and PBL are both student-focused and work together harmoniously. This methodology has been implemented successfully at various universities, including Rice University [5]. The flipped classroom approach offers many benefits,

such as empowering students to take ownership of their learning and problem-solving techniques. Nonetheless, some students may respond negatively to the added personal responsibility that comes with this approach, which is a common challenge in flipped classrooms [5].

For Make to Innovate, some adjustments were made due to the scale of the program, the number of projects involved, and the breadth of engineering topics involved. Many implementations of PBL and flipped classrooms tend to use smaller classrooms that may contain students from twenty to fifty students [6]. M2I has averaged around one-hundred and fifty students with a peak of two-hundred and eighty students. This required additional faculty and staff to assist students in both learning and helping the students achieve their goals.

Our projects require various disciplines' expertise to tackle many challenges. For instance, a rocket project involves the collaboration of aerospace, mechanical, chemical, electrical, and computer engineering disciplines. As a result, students from diverse backgrounds and with distinct career aspirations must collaborate to overcome the obstacles. This diversity fosters a team-based and interdisciplinary learning approach that provides students with invaluable insight and skills beyond those learned in a typical classroom setting [7].

Program Philosophy

At Make to Innovate, we advocate for a practical learning experience emphasizing a hands-on approach. Our students are motivated to tackle problems head-on and create innovative solutions that can be tested in real-world scenarios. Clear objectives are set for each project, emphasizing design, construction, and the iterative learning process. Our motto, "Design, Build, Learn," encapsulates our philosophy of learning by doing and that learning is an iterative process. This iterative process helps strengthen students' creative thinking, an essential part of the design process [8].

Our commitment is to equip our students with skills that transcend traditional engineering education. As emphasized by Cox et al, engineering students today require supplementary skills beyond the classroom's confines [9]. Additionally, the Accreditation Board for Engineering and Technology (ABET) mandates that engineering students learn skills other than mathematics, science, and engineering [10]. Through our hands-on approach, students learn to work in a team environment, collaborating to solve problems presented by their projects [11].

Learning Outcomes

As with any course, Make to Innovate has learning objectives that help define and guide how the program is executed. These learning outcomes focus on multiple skills, including engineering, project management, and professional development skills. These outcomes define our objectives for each class and what we expect the students to learn through the process. The following are the general learning outcomes for both courses.

- Develop communication skills, written and oral, to work within their team's process and results.
- Develop skills in working in a team.

- Develop engineering skills to design, build, and test a product.
- Develop a work plan and objectives to complete their project.
- Understand and develop design requirements.

Students who are enrolled in courses with three credits and who also hold leadership roles have the opportunity to acquire valuable additional learning outcomes. These outcomes entail the acquisition and enhancement of leadership skills, as well as the development of more advanced project management skills. These skills are highly valuable and can give students a competitive edge in their future careers.

Our sophomore-level course is designed as a one-credit offering tailored to first- or second-year students. While we anticipate that these students have a basic set of engineering skills, our primary focus is to provide opportunities to develop them through hands-on tasks and mentorship from their upperclassmen peers. We intentionally mix under and upper-class students in teams to foster a collaborative learning environment.

The advanced-level course builds upon the foundational concepts of the previous course and includes additional learning objectives. As students progress to this level, we anticipate a more significant engagement level, reflected in the increased credit requirement from one to two. Students at this level also have the opportunity to take on a leadership role, either as a project leader or team leader. Those who choose to do so must take the course for three credits.

The instructors assign student leadership roles based on their interests, abilities, and past leadership experience. At the beginning of the semester, students are asked to complete a survey indicating which project they wish to serve on and if they are interested in a leadership position, along with reasons why. By evaluating this information, we can identify students who would excel in leading their teams and projects. Additionally, we value student feedback and often promote individuals who meet our requirements and are requested by their peers. Those who take on leadership roles will use their professional and project management skills more than their engineering skills. When accepting a leadership position, we advise students to expect a heavier workload to manage their team or project and reduce involvement in solving engineering problems.

Problem Statement

Over the last twelve years that the program has been operating, many challenges and issues have been identified. The non-traditional nature of the program presents interesting challenges as it is often seen as a departure from more traditional classroom structures. Over the years, we have continuously assessed the program and implemented various changes as we grow and learn from what works and doesn't.

Assessment challenges

Many of these issues revolve around assessing the students enrolled in the program. The first of these issues is how one accurately assesses how well a particular student performs in class. Each

student may be studying different degrees, and with that comes different skill sets. Additionally, other students have different expectations, and with the flipped classroom approach, there are more nuances due to different student personalities and how that affects the learning process. Furthermore, how does one determine which students put forth the work and effort worthy of an A letter grade compared to students doing B or C quality work? This has evolved a lot throughout the M2I program and will continue to evolve to improve the methodology and hopefully find the optimal way to assess this style of class.

In recent semesters, we have been using a combination of having students submit their time spent on the project, with a minimum number of hours required per credit hour, and submitting a short presentation, often referred to as a quad chart. An example of this quad chart is shown in Figure 2. The quad chart has four quadrants where students enter information, including the tasks assigned and hours spent on each task, the deliverables associated with each task, any risks/blockers that students ran into during the week, and any discussion they may have. Following that slide, students are expected to have more slides discussing the tasks they worked on and the objectives they accomplished for the week.

The issue with this current setup is that students would present these slides to their group in weekly meetings, verbally discuss their work, and submit them as is, so when it comes time to grade, the work appears to be less. Secondly, since students were required to average a set number of hours each week, many would log the average number of hours needed to get an A every week regardless of how long they worked and how simple the task was. For example, many underclassmen taking the one credit hour class were required to have three hours of work logged a week on average to get an A in that part of the course, and almost all the students would magically log exactly three hours every week for every task. This has led to a newer implementation of grading discussed later in this paper.

Student Assessment Strategy

We have modified our students' assessments to tackle their challenges. We have categorized the assessment into three parts: Student Achievements, Project Achievements, and Student Growth. These categories are further divided into individual and group scores. The individual scores of Student Achievements and Student Growth carry a weightage of 60% of the total grade. The remaining 40% of the grade is based on the group score of Project Achievements. This distribution of scores ensures that individual efforts are the major contributing factor towards the final grade.

Our Student Growth assessment focuses on developing the lifelong learning skills that we want our students to have. As part of this program, we arrange talks where industry experts and alums discuss various topics, from technical skills to job placement and professional development skills. Attending at least one of these talks is mandatory for students. Our program also benefits from our connections with major industries such as Boeing, Collins Aerospace, Honeywell, and others, which allows us to provide students with valuable insights and opportunities.

Students are then allowed to attend additional talks, various workshops we hold, or conduct an outreach event. Students must attend at least two of these for a total of three events that they attend or participate in. Some of the projects in our program need to conduct an outreach event to

Assigned Tasks (1 pt)	Expected Deliverables (1 pt)
• List the tasks you have been assigned • Reference the YouTrack ID, for example: • TEST-22 Demonstration Task • Indicate how many hours on each one	• List the deliverables that was expected for each task • Put the due date next to it
Accomplishments (1 pt)	**Task Bottlenecks (1 pt)**
• Give a brief summary of your accomplishments • These should be related to your assigned tasks, but other accomplishments can be listed • as long as they are related to the project and your role in the project	• If you had any task bottlenecks, put them here • For Example: “Waiting for something to 3D print” or “I did not allocate enough time to finish this task” • Saying ”I was busy with classes” does not count • If you accomplished everything you did, simply state that you accomplished everything

Figure 2: Example of a student quad chart that would be submitted.

Item	Issue Summary	Date	Author	Type	Comment	Spent time	Estimation
TEST-14	Task 1 - Record video to show how to log time in YouTrack	2024-01-19	REMOVED	Documentation	This was time spent in actually making the video and doing a demo of it.	1h	56h
TEST-14	Task 1 - Record video to show how to log time in YouTrack	2024-01-19	REMOVED	Documentation	Accomplishments Created some example tasks that will be used in the video. Time was also spent in cleaning up some of the issue types and states in YouTrack. All projects should now have a uniform set of these and some of the confusing ones have been removed. A comment was added with a screenshot that shows one of the example tasks to be used in the video.	3h	56h
TEST-17	SubTask 1	2024-01-16	REMOVED	Documentation	Recorded a video showing how to log time in YouTrack. Video is up on Canvas.	2h	3h
TEST-21	Task 3	2024-01-17	REMOVED	Documentation	More comments	8h	8h
Total:						**14h**	

Figure 3: Example of a report generated from YouTrack.

fulfill a requirement for the competition that we are competing in. This allows them to count those events and not put extra pressure on those projects.

Our Student Achievement assessment employs two methods to assess the students’ contributions and the extent of those contributions. The first approach involves all students presenting their work during weekly meetings with their teammates. To summarize their work, students use a Quad Chart, which is shown in Figure 2, followed by additional slides to demonstrate their work. TAs grade the presentations during these meetings.

The second method involves all students logging their activities and the time spent on them in a software program called YouTrack by JetBrains. They must generate a report from YouTrack, which is then submitted to our Learning Management System (LMS). Figure 3 shows an example of this report. These reports include the duration of their activities, the nature of their work, their complexity level, and the number of tasks they were assigned for that particular week. We use this information to calculate a score contributing to their overall grade.

To evaluate the project achievements as a whole, we use two methods. The first method is through monthly meetings with each project leadership group. Project leaders will present the project’s status, any major issues, and the project’s overall health. This allows us to assess the project’s

progress and provide instant feedback to the students.

For the second method, the assessment begins at the beginning of the semester. At the beginning of the semester, students are required to submit a charter for their projects. This charter includes three deliverables that the project will submit. They then work towards completing three deliverables, which must be submitted no later than the end of the semester. The students then showcase their completed projects at the Exposition, attended by the M2I faculty, staff, TAs, and members of the Iowa State University community. The Expo is an opportunity for the students to demonstrate their achievements and hard work.

Implementation with a systems engineering approach

Since its inception, Make to Innovate (M2I) has always aimed to introduce students to group project learning and management, allowing them to gain skills that help them acclimate better from academia into industry. Throughout the years, M2I went from a project structure of only one leadership role within a project to breaking that leadership role down into a Project Manager and multiple team managers hierarchy. We have adopted this more systems management approach based on several factors we have encountered over the years.

M2I has a relatively stable set of core projects set that continues across multiple academic years. These stable projects usually provide leadership for the project through students who have already been on the project. These students have a unique internal understanding of the project and what needs to happen to make it successful. We rely on these students as the first touch point for interaction between the project group and the class staff. They become the project managers of their respective groups. Projects that chose this project manager themselves versus being chosen by M2I staff are usually projects that have a higher success rate.

After watching teams for years try to progress a project without any input from staff about how to manage a group, we turned to industry research to better understand and help projects finish their goals. Much of this research has been done on the software side of project management, but we have found that it has also worked well in our classroom situation. According to Doug Putnam, QSM Vice President, in 2005, a team of three to seven people performed best in effort, progress, and productivity [12]. We used this research as a starting point and have found that our projects, when broken down into two or three teams of six members, can produce the deliverables they set out to accomplish every semester with fewer students being able to coast through without providing project input. A typical project within M2I has 13 members, three in leadership positions and ten as team members. A typical project organization structure can be seen in Figure 4. This leadership group allows the project manager to have students they trust to bounce ideas off of and shoulder some burden of ensuring all team members have tasks to work on during the week. These tasks are a metric on which they are graded.

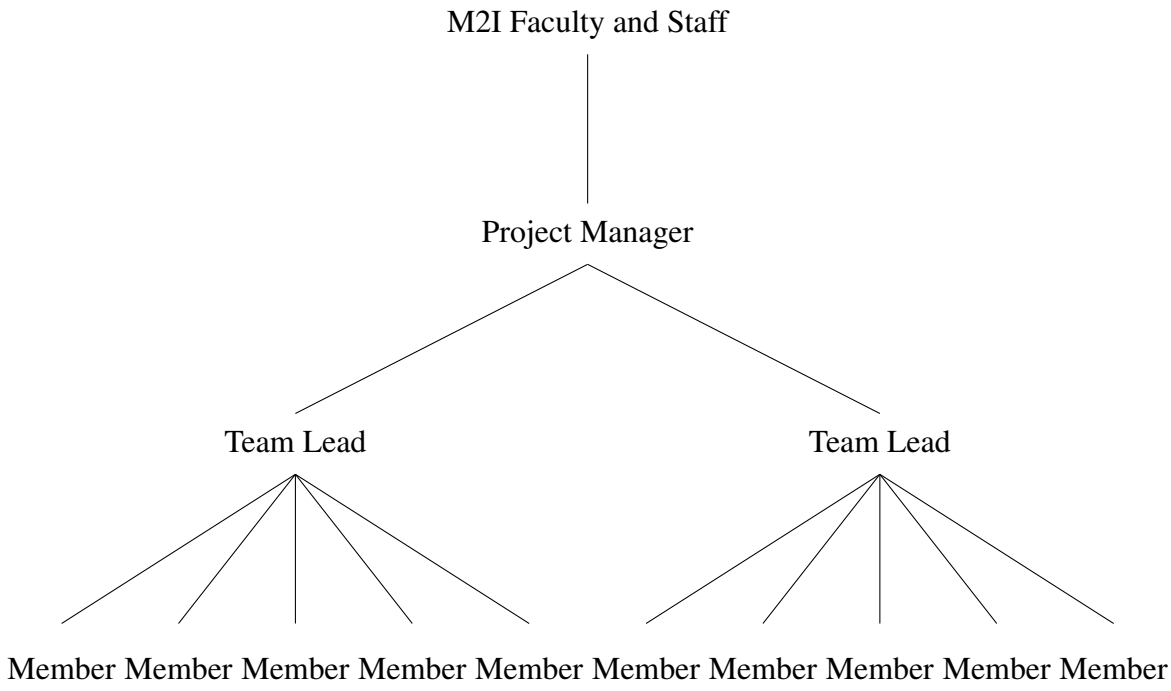

Figure 4: M2I Project Structure

By implementing leadership-generated tasks, personally created tasks, and using those tasks as a grading metric, we introduced a systems approach to project management versus an analytical approach. Both the leadership of the project and the students themselves can look at their project and break down what needs to be done on a project, system, and personal level much better than when an analytical approach was taken. The analytical approach looks too in-depth at a problem and causes students to focus too much on specific issues [13]. Within engineering, this is the approach that is typically chosen. A focused approach works at a personal level, with small tasks, but if there is no manager above them, ensuring that what they are focused on is needed to move the project forward, projects get derailed and stalled quickly. Most of our projects make significant progress every semester by having students in management positions who are expected to put in the vast majority of their time specifically toward looking at the project as a whole and taking a top-down approach to project management.

Through many iterations, the staff of M2I have tried to find ways to allow the projects to move forward without program staff micromanaging. We tried a monthly check-in with the student leadership and program staff where the students presented about project progress, student engagement through hour tracking on tasks, and overall feelings about the team over the month and moving forward. We found that more oversight was needed for students individually, and more assessment of project input was needed. It appeared that students would not accurately track their progress without the requirement of a weekly assignment. Grading student performance by hours alone was not feasible within academia, as the ebb and flow of tests throughout the semester hindered the students' ability to work on weekly tasks consistently. It was also noted that students seemed to log the exact hours required to get their desired outcome. To counter this, we implemented the equation as shown in Equation 1. This equation factored in task difficulty as

assigned by the staff, tasks assigned, tasks completed, and hours worked to allow grading to be more balanced among student skills at the different academic levels. We are still currently analyzing this strategy.

$$K\left(\frac{\text{completed tasks}}{\text{assigned tasks}}+\frac{\text{number of hours}}{\sum\text{task difficulty}}\right)\geq 1 \tag{1}$$

The M2I program constantly evolves to ensure students learn valuable industry-desired skills without feeling overwhelmed by menial tasks. There is a balance to be struck that the program achieves when we listen to student feedback as well as our industrial partners. This program works because we constantly evolve to create the most hire-able students available.

Results

The Make to Innovate program employs a range of methods to evaluate the effectiveness of its approach. The first method involves leveraging a university course evaluation tool, which assesses diverse aspects such as the teacher's competence, the elements contributing to student learning, and the factors hindering it. The second tool is the Comprehensive Assessment of Team-Member Effectiveness (CATME) survey developed by Purdue [14]. This assessment is conducted twice a semester. The primary purpose of this survey is to provide insights into how healthy teams and projects are functioning, but students can also provide feedback in a comment box. Unlike course evaluations, students must complete CATME surveys as a graded assignment, resulting in a high response rate of 90-95%. This survey enables students to provide negative and positive feedback, and we can make mid-semester adjustments based on their comments. On the other hand, course evaluations are only available after the semester, which limits our ability to make timely changes to the ongoing semester.

As a part of our program, we have an informal resource that we utilize to gather feedback from our students. We regularly convene with project leadership teams every month to seek out students' input and discuss ways to enhance the program. These meetings provide a platform for students to share their feedback and ideas, which we value greatly. We have received candid feedback from numerous students in the past, and we have successfully incorporated their suggestions to refine and improve the program.

Student Achievements

One of the program's biggest successes is the remarkable success of our students who have participated in our program. Throughout the years, more than four hundred students have completed our program and have gone on to achieve great things. Our program has sent over twenty-five teams to various national competitions, resulting in over fifteen awards. Additionally, our students have participated in over thirty outreach events, and we have hosted more than thirty talks. Notably, many of our students have gone on to work at esteemed companies like Boeing, Collins Aerospace, Honeywell, and many others.

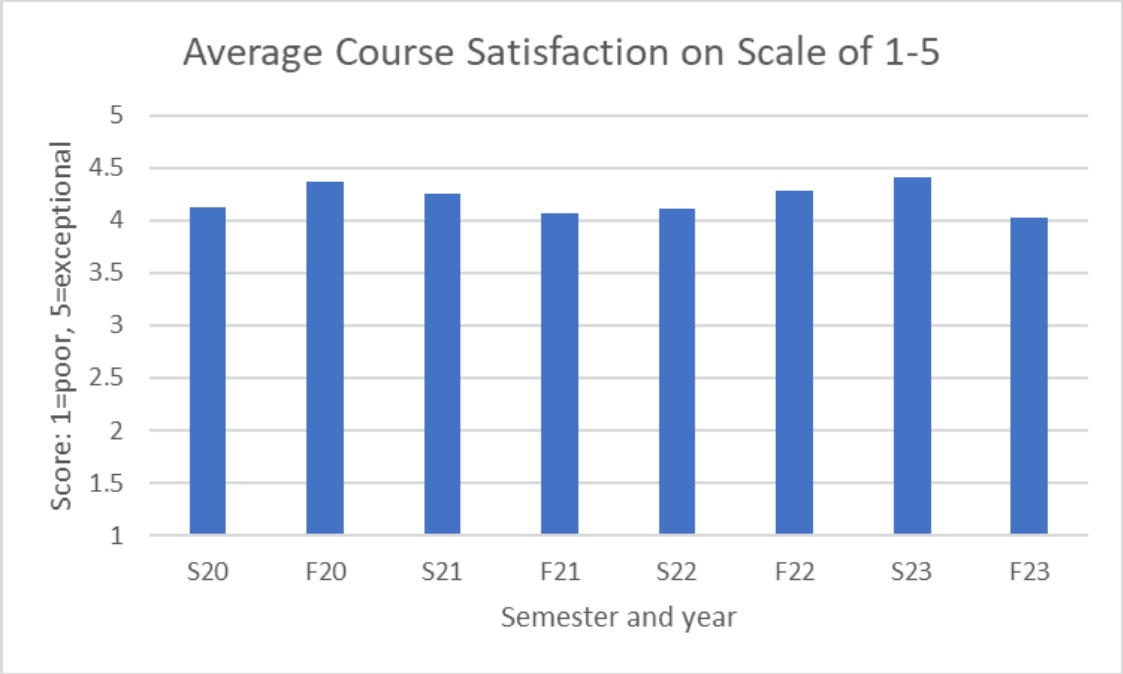

Figure 5: Overall course notification over the last three years.

Student Reactions

Students have had a largely positive reaction to the program. Through the course evaluations, students have evaluated the program with overall positive results. On a five-point scale, with one being poor and five being exceptional, our average score is a four. A graph of our evaluation scores over the last three years can be seen in Figure 5.

Students routinely inform us that they enjoy being in the program and the impact that it has had on them. Alumni have also reported back to us stating that the program has not only helped them get a job, but has better prepared them for work in industry.

The following are some quotes that we have collected from both the course evaluations, which are anonymous, and the CATME surveys. These quotes help to show the positive impact the program has had on the students.

> "The freedom to work on whatever we'd like. I personally love being able to fail at tasks and goals that I've set out for myself because I know that I'm failing at something that I actually want to learn. In comparison to a normal class structure, where if I fail at something, it hurts more because I might not be as interested in learning it, yet it still affects my GPA"
>
> "Freedom to learn and understand coursework material and apply to real world problems from class. Recommended to all engineering majors."
>
> "Asking questions within my team. It helped me learn a lot about the direction that the project is going, as well as many different skills, such as latex documentation,

soldering, and wiring electrical components."

"Hands-on learning is the best way to achieve your career goals. Having amazing equipment available in the M2I lab is helpful for every situation. Each project is creative, and the entire environment is encouraging and exciting to be a part of."

"The very nature of the course is amazing for learning. Getting to actually get my hands dirty with the MAVRIC rover is amazing. There are also a lot of peers to consult that know what they are doing since the class is formatted so the freshman and seniors and even grad students can all be in the same room working together."

"M2I is my favorite class I've ever taken. I'm very grateful for all of the opportunities it has given me thus far and I'm very excited for next year."

"This was my first semester in M2I, and I really enjoyed the work I've been doing. The connections I've made with people from my major and others are amazing, and I'm looking forward to working with them next semester as well."

"The instructors have been great in not making this experience stressful or negative; both Matt and Christine have been super helpful in providing the resources and information needed to make effective progress this term given the hand we were dealt, and I have come to enjoy being within M2I because of it. I hope my occasional questions are never a bother to the instructors; I would rather ask dumb questions than assume the wrong answer. This opportunity has also been an amazing talking point during interviews; this project was the sole topic of discussion for a Spirit internship in Kansas for which I received an offer, so I am grateful to have had the chance to learn from this role in the project and apply it directly to my career; it has helped me greatly and crucial to my success. Thank you for making the experience on the team positive, and I hope Christine and Matt hold this project to an ever-increasing standard; I am excited to see where things go from here."

"I had a lot of fun this semester learning about electrical systems for aircraft. My knowledge level in this area has significantly gone up and I am very glad to have been able to be a member of Cardinal Flight."

"Thank you for allowing us to work on a project like this. I enjoy the different pace from the standard courses. I also enjoyed the creative learning modules. I feel like the things discussed in those modules can improve all courses in the engineering program. "

"This is my first semester of M2I and I have had nothing but positive experiences from it. Thank you for providing a fun space to apply my learning!"

"I just wanted to say thank you for this opportunity to gain leadership skills and project experience. It did wonders for me when I was searching for jobs, and I give a lot of credit to this for getting a job at Boeing."

"This is a very good class that allows for hands-on experience. The projects are very interesting and allow for students to see various aspects of this future career. "

Lessons Learned

After running this program, a few lessons have been learned on how to implement this type of course and how not to implement this type of course. Throughout running this program, we have improved how we approach the pedagogy and assess the students' progress in the program. The following is a summary of the lessons learned discussed in this paper.

Assessment Challenges and Adaptations. At first, there were challenges in ensuring a fair and inclusive evaluation of the student's performance and growth within the program. Nevertheless, we tackled these obstacles by establishing a system for weekly reports, arranging regular meetings with students to offer and receive feedback, and including presentations of their work during these meetings. Additionally, peer assessments utilizing CATME have proven invaluable in comprehensively evaluating student progress and their ability to meet learning objectives.

Managing Diverse Student Groups. The program faced challenges managing various student backgrounds and ensuring projects remained on track. Project leadership structures were refined, with project managers and team leads designated to facilitate project management and execution. This hierarchy helped in distributing responsibilities and ensuring project goals were met. It was also noted that having courses set up to be arranged instead of for set class time creates additional hurdles. Many students sign up for the course and are confused about when they will meet or have conflicts with the meeting time. Moving forward, we plan to set up sections for our projects and set times in advance to avoid such conflicts.

Use of a Systems Engineering Approach. To improve both the management of projects involved in the program and to provide students with additional skills, a systems engineering approach was adopted. Adopting a systems engineering approach helped manage projects more effectively, especially as the program scaled. This approach allowed for better overall project oversight and individual task management, contributing to the program's success in delivering meaningful engineering education experiences. In addition, some skill sets can be taught to students to give them a better appreciation of using a systems engineering approach.

In summary, the program has learned to balance the dynamic nature of project-based learning with the need for structured assessment and management approaches. Continuous adaptation, informed by feedback and educational research, remains vital to its success and relevance.

Future Work

This program has been and will continue to be under revision. The way that students learn is constantly in flux, and for a program to be successful, it needs to grow and adapt to the needs of the student while still maintaining the learning objectives that have been established. The next generation of the program needs to adapt to the changing landscape of engineering education. As shown in Figure 6, we need to blend students' learning with how they use that knowledge and allow them to be innovative and creative in their thinking.

As we have observed through our lessons learned, first and second-year students often need more skills to excel in a project-based learning course, such as the one we offer. We propose a new course sequence that includes class time to cover these topics and equip students with the

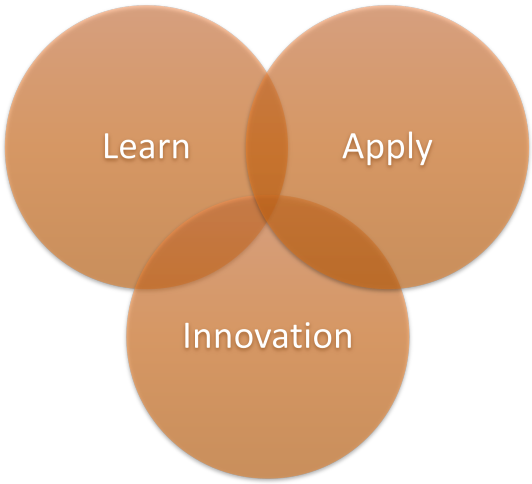

Figure 6: The three tenants for the program for the next generation of students.

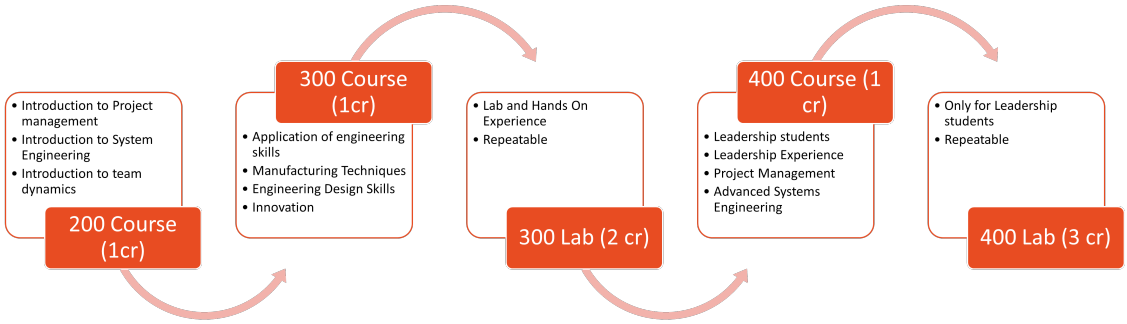

Figure 7: Proposed new sequence of courses for the program.

necessary tools to succeed. By teaching students these skills early on in their academic careers, they will be better prepared for our program and have an advantage in other courses that require group projects or hands-on learning. We will help them with our program, but we theorize this will also help them with other courses, especially those with group projects or hands-on learning.

The proposal comprises a comprehensive curriculum that spans three levels of study. At the sophomore level, students will be taught project management, time management, team dynamics, and basic systems engineering skills. Upon completing this stage, they will progress to the junior level, learning about manufacturing techniques, engineering design, and innovation. Finally, at the senior level, they will explore advanced topics such as leadership, teamwork, project management, and system engineering. To ensure an immersive learning experience, two lab courses will be offered, with the senior-level course being exclusively reserved for students in leadership roles. A tentative outline of the courses we are working on is shown in Figure 7.

Conclusion

The purpose of this paper is to provide a detailed account of the Make to Innovate program's history. We wanted to explain why we adopted our specific strategy and pedagogy approaches. Our program has been operational for many years, and over this time, we have continuously adjusted it to cater to the needs of students and meet our objectives.

We implemented the Make to Innovate program to provide students with practical, hands-on learning. This approach helps students develop critical thinking skills, promotes creativity and innovation, and prepares them for real-world challenges. To achieve these goals, we adopted a strategy that focuses on project-based learning. This approach encourages students to work collaboratively, learn from each other, and tackle real-world problems.

Our pedagogy approach is centered around the idea of learning by doing. We encourage students to experiment with different materials, tools, and techniques to develop their skills. Our instructors act as facilitators and guides, providing students with the necessary resources, support, and feedback to help them achieve their goals.

Over the years, we have continuously evaluated the program's effectiveness and made changes to improve it. We have added new projects, updated our curriculum, and incorporated new technologies to enhance the learning experience. We aim to ensure the program remains relevant, engaging, and meaningful to students.

In conclusion, we have discussed the Make to Innovate program's history, strategy, and pedagogy approaches. We have also highlighted our plans for the program's next generation as we aim to continue innovating it. We hope this paper provides a comprehensive understanding of our program and its impact on students' learning outcomes.

References

[1] A. Gero, "Students' attitudes towards interdisciplinary education: a course on interdisciplinary aspects of science and engineering education," *European Journal of Engineering Education*, vol. 42, no. 3, pp. 260–270, May 2017. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/03043797.2016.1158789

[2] A. Yadav, D. Subedi, M. Lundeberg, and C. F. Bunting, "Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course," *Journal of Engineering Education*, vol. 100, no. 2, pp. 253–280, Apr. 2011, mAG ID: 2137085812.

[3] A. Wiek, A. Xiong, K. Brundiers, and S. van der Leeuw, "Integrating problem- and project-based learning into sustainability programs: A case study on the School of Sustainability at Arizona State University," *International Journal of Sustainability in Higher Education*, vol. 15, no. 4, pp. 431–449, Aug. 2014. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/IJSHE-02-2013-0013/full/html

[4] A. C. B. Reis, S. C. M. Barbalho, and A. C. D. Zanette, "A bibliometric and classification study of Project-based Learning in Engineering Education," *Production*, vol. 27, no. spe, 2017.

[5] A. Saterbak, T. Volz, and M. Wettergreen, "Implementing and Assessing a Flipped Classroom Model for First-Year Engineering Design," *Advances in Engineering Education*, vol. 5, no. 3, p. 29, 2016.

[6] B. Kerr, "The flipped classroom in engineering education: A survey of the research," in *2015 International Conference on Interactive Collaborative Learning (ICL)*, Nov. 2015, pp. 815–818, mAG ID: 1928020690.

[7] M. Nelson, B. Ahn, and C. Nelson, "Make to Innovate: Blending of Project-based Learning and Flipped Class-room Pedagogies to Provide Real-world Engineering Experiences to Engi-neering Students," in *2019 ASEE Annual Conference & Exposition*, Tampa, FL, 2019. [Online]. Available: https://peer.asee.org/33074

[8] M. K. Foster, "Design Thinking: A Creative Approach to Problem Solving," *Management Teaching Review*, vol. 6, no. 2, pp. 123–140, Jun. 2021. [Online]. Available: http://journals.sagepub.com/doi/10.1177/2379298119871468

[9] M. F. Cox, C. Osman, B. Ahn, and J. Zhu, "Engineering professionals' expectations of undergraduate engineering students," *Leadership and Management in Engineering*, vol. 12, no. 2, pp. 60–70, 2012.

[10] L. J. Shuman, M. Besterfield-Sacre, and J. Mcgourty, "The ABET "Professional Skills" - Can they be taught? Can they be assessed?" *Journal of Engineering Education*, vol. 94, no. 1, pp. 41–55, 2005.

[11] M. E. Nelson and B. Ahn, "Improving engineering students professional development skills in the Make to Innovate program," in *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN, 2017, pp. 1–5.

[12] D. Putnam, "Team Size Can Be the Key to a Successful Project." [Online]. Available: https://www.qsm.com/articles/team-size-can-be-key-successful-project

[13] J. R. Meredith, S. M. Shafer, and S. J. Mantel, *Project management in practice*, 6th ed. Hoboken, NJ: Wiley, 2017.

[14] M. W. Ohland, M. L. Loughry, D. J. Woehr, L. G. Bullard, R. M. Felder, C. J. Finelli, R. A. Layton, H. R. Pomeranz, and D. G. Schmucker, "The Comprehensive Assessment of Team Member Effectiveness: Development of a Behaviorally Anchored Rating Scale for Self- and Peer Evaluation," *Academy of Management Learning & Education*, vol. 11, no. 4, pp. 609–630, Dec. 2012. [Online]. Available: http://journals.aom.org/doi/10.5465/amle.2010.0177