Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #47032

Bridging the Gap: Integrating Entrepreneurial Thinking and New Product Development into Manufacturing Education

Dr. Gimantha N Perera, University of Arizona

Gimantha Perera is a Postdoctoral Scholar/Research Scientist in Systems and Industrial Engineering at the University of Arizona. His professional areas of interest include augmented reality application, healthcare systems engineering, and broadening participation in engineering, particularly at public institutions. Gimantha is focused on assisting a small engineering education task force at UA studying asset-based practices, building communities of practice, industrial engineering education, and the formation of professional identities.

Hannah Budinoff, The University of Arizona

Hannah Budinoff is an Assistant Professor of Systems and Industrial Engineering at the University of Arizona. Her research interests include additive manufacturing, geometric manufacturability analysis, design for manufacturing, and engineering education.

DAVID MANFORD, The University of Arizona

Bridging the Gap: Integrating Entrepreneurial Thinking and New Product Development into Manufacturing Education

Gimantha N. Perera, Hannah Budinoff, David Manford*

Systems and Industrial Engineering, University of Arizona, Arizona, USA

Abstract

Programs and resources aimed at fostering innovation and an entrepreneurial mindset are now common across many institutions of higher education. However, industrial engineering students often engage minimally with available innovation and entrepreneurship (I&E) opportunities at our institution. This project sought to address this challenge at a large public land-grant institution, aiming to increase student engagement with these resources. Recognizing that engineering students tend to prioritize activities that earn course credit, the project focused on bridging the gap between entrepreneurship and engineering. The primary objective of the project was to redesign a required third-year industrial engineering course with a typical enrollment of 50 students to emphasize New Product Development (NPD) and practical manufacturing skills. The redesigned course aimed to connect students to I&E resources while providing hands-on experiences they could use to ground their skills in both manufacturing and entrepreneurial thinking. This initiative involved two key components: the introduction of entrepreneurs into the classroom and the implementation of a hands-on NPD project. Guest entrepreneurs led discussions on real-world challenges in product development while students worked on projects designed to simulate the process of taking a concept to market. Student feedback was collected through surveys, which measured entrepreneurial mindset, identity development, and perceptions of the relevance of I&E education in the context of manufacturing.

The evaluation data suggests that students valued the connection between manufacturing theory and entrepreneurial practices. Survey responses indicated that exposure to I&E concepts and resources in the course helped students develop an entrepreneurial mindset and identity. Additionally, the inclusion of guest entrepreneurs and mentoring for practical NPD projects helped bridge the gap between academic concepts and real-world manufacturing challenges. However, some students felt that this experience came too late in their curriculum to make a significant impact, that the I&E content did not add new insights, and that the implementation did not foster the level of creativity or autonomy they desired. Despite these concerns, the majority of students responded positively, indicating that their labs and projects prepared them for future endeavors and appreciated the limited autonomy to explore their own ideas. The integration of entrepreneurial education into the manufacturing curriculum has shown promising results in encouraging engineering students to engage more deeply with I&E programming. The outcomes of this project suggest students see some value in I&E content integration and that there exists a viable path for other engineering departments to foster entrepreneurial thinking in their students. Students' preferences suggest including I&E content early in their academic careers and increasing autonomy in projects if included in the third year. The methods utilized in this project need adjustment to better fit student expectations and engage a broader subset of students. Future research could build on this work to explore the long-term effects on student outcomes and the broader impact on participation in the I&E ecosystem.

1. Introduction

The integration of entrepreneurial thinking into engineering education has long been employed as a means of fostering innovation, enhancing career readiness, and equipping students with the interdisciplinary skills needed to address complex industrial challenges (Yu et al., 2024). The Accreditation Board for Engineering and Technology (ABET) echoes the need for such skills by including teamwork, communication, and entrepreneurship as requirements for engineering programs. (Fang, 2011). Despite this emphasis, many students favor traditional technical competencies over interdisciplinary skills due to engineering curricula lacking opportunities to practice entrepreneurial skills (Mohammed, 2021).

Entrepreneurship in engineering education has historically cultivated students' ability to identify opportunities, design innovative solutions, and navigate market demands (Yu et al., 2024). Several institutions have successfully implemented entrepreneurial initiatives through project-based learning and cross-disciplinary collaboration, often leveraging courses as platforms for bridging technical and business acumen (Watson et al., 2017). Courses that feature student-driven entrepreneurship projects enhance student engagement and provide a practical context for applying engineering concepts, fostering a deeper understanding (Cox, 2017; Osta, 2023; Ssemakula, 2002).

Due to reports of underutilization of innovation and entrepreneurship (I&E) resources among engineering students at our institution, this study redesigned a third-year manufacturing-focused industrial engineering course to integrate with I&E resources on campus. A hands-on project component of the course was added to integrate New Product Development (NPD) and the application of practical manufacturing skills. By including an entrepreneurial component, the course aimed to connect students with existing I&E resources and provide hands-on experiences that simulate real-world manufacturing and business challenges. We also introduced a guest entrepreneur guest speaker, who shared insights on the challenges and strategies of product development. This aligns with prior successful implementations of entrepreneurship-focused manufacturing projects, where experiential learning was used to train I&E skills(Fang, 2011; Osta, 2023).

Furthermore, the initiative sought to assess the effectiveness of integrating I&E concepts by collecting student feedback on entrepreneurial mindset development, identity formation, and perceptions of the relevance of I&E education in manufacturing. This paper aims to contribute to manufacturing education by providing insights into the design, implementation, and outcomes of integrating entrepreneurial thinking into manufacturing curricula.

2. Background

The University of Arizona (UArizona), a public land-grant and Hispanic-Serving Institution (HSI), has a strong ecosystem for promoting technological innovations. As a highly ranked public research institution, our diverse engineering student population has many opportunities to engage with faculty in innovative research and coursework on new technologies. Additionally, students have access to free, asynchronous programming to promote an entrepreneurial mindset and develop their own startups. Students can also apply for formal mentorship through the startup process.

Engineering education has long emphasized the importance of equipping students with hands-on experience to solidify theoretical concepts, particularly in manufacturing disciplines. Research underscores that practical engagement enhances student understanding of complex topics like manufacturability, scalability, and product development (Cox, 2017; Ssemakula, 2002). Despite this, many engineering programs fail to integrate entrepreneurial thinking into their curricula, leaving students underprepared for the dynamic challenges of scaling ideas to marketable solutions (Da Silva et al., 2015).

At the University of Arizona, while programs outside of engineering curricular programs offer resources, the lack of course-embedded initiatives limits student engagement. Engineering students often prioritize academic activities that earn course credit over extracurricular ventures, creating a disconnect between innovation opportunities and manufacturing education. This gap is especially pronounced in industrial engineering, where courses rarely focus on new product development (NPD), a critical step in bridging theory and practical implementation.

This initiative builds on established educational theories emphasizing the benefits of experiential learning in fostering creativity and entrepreneurial skills. Studies highlight that integrating entrepreneurial education in engineering programs not only improves technical competence but also prepares students for real-world challenges by enhancing their problem-solving abilities and entrepreneurial identity (Bielefeldt et al., 2018).

3. Course Redesign Framework

The objectives of the course are to understand basic primary and secondary manufacturing processes and to understand the integration of part design and manufacturing. And to understand concepts and experience tools for manufacturing. Topics that are covered include basic manufacturing definitions, functions, and systems; part design specification, including dimensioning and tolerancing, CAD systems, manufacturing processes, tooling and fixturing, and lean manufacturing concepts.

Prior to the course updates, the focus of the course was mostly on remembering and understanding key topics. Our project aimed to incorporate New Product Development and entrepreneurial thinking in the course and to provide more opportunities to apply, evaluate, and create based on covered topics. This course redesign included the introduction of a course project, providing students with knowledge about I&E resources on campus, and highlighting small business owners and entrepreneurs in manufacturing industry through a guest speaker and industry tours.

For the team project, teams of four students engaged in hands-on projects to prototype and plan the scale-up production of products using manufacturing techniques discussed in class. The student teams were tasked with identifying their own unmet need in their community or lives to design and prototype as part of the project. After identifying a need, students interviewed potential users to compile needs, brainstormed solutions, and started to design and prototype their solutions. Key deliverables for the projects included CAD models and engineering drawings with tolerancing of key features. The students were also asked to describe their manufacturing plan for at-scale production, identifying potential manufacturing processes to fabricate their products. Students were asked to solicit feedback on their design from potential users and incorporate changes. Finally, students presented to their peers in a "pitch day" event, where the class voted for the product that they would like to invest in, hypothetically.

The course project deliverables mostly focused on technical aspects of new product development, but we also incorporated I&E resources in hopes of sparking students' interest in exploring business concepts such as market viability. We also asked them to estimate some manufacturing costs and to look at the price of other similar products.

To incorporate I&E resources, we invited the campus's student-facing I&E program to come into class and present to students the entrepreneurial resources, such as the Student Prototyping Mini-Grants program. Through this program, we also invited a guest lecturer who had founded a local industrial sewing company to come speak during class. This speaker described her experience with founding a company and offered guidance on navigating commercialization pathways. Similar themes were also discussed on industry tours.

We found that there were several areas in which the I&E content aligned well with course objectives. Students' skills with dimensioning, tolerancing, CAD, and engineering drawings were all applied in the course project. Students also applied their knowledge of manufacturing process selection to provide a manufacturing plan to produce their products. In future years, the project could also be expanded to support the application of other course objectives (e.g., students could provide a production schedule based on their estimated demand over a year and their product's bill of materials).

4. Methodology

This project employs a mixed-methods approach to evaluate the impact of the redesigned course. Key metrics and data collection methods include curriculum feedback and entrepreneurial identity development measures. For curriculum feedback, we used student surveys using qualitative and quantitative measures to assess perceived relevance and engagement as well as qualitative feedback from students on the engagement of guest speakers. To measure entrepreneurial identity development, we used surveys on perspective to measure shifts in entrepreneurial passion and perceptions of the university environment (Cardon et al., 2013; Franke & Lüthje, 2004). Appendix A contains the outline of the survey used to capture entrepreneurial identity and curriculum feedback.

Demographic data was provided on a voluntary basis with aggregated ranges and selections to ensure anonymity. Quantitative data was visualized using descriptive statistics to understand the general perception of using an NPD-focused project as an intervention in the course. Perceived ratings from students were used to quantify students' comfort levels with entrepreneurial concepts, the impact of small group activities, the perceived value of labs, the perceived value of tours of external facilities, and the perceived value of the redesign in training skills that might be useful for engineering senior capstone projects. Qualitative data justifying ratings was used to contextualize the students' feedback and determine the exact causes for high or low scores. This data was gathered using a structured bipolar ladder, which is a variation of a bipolar ladder (Pifarré et al., 2009; Pifarré & Tomico, 2007). A technique that asks respondents to rate an element of interest from -5 to 5, depending on whether they view it positively or negatively, and justify the rating with a qualitative response.

We also counted the entrepreneurial skills gained due to the course redesign, as self-identified by students. The skills-gained data was also accompanied by qualitative data on specific examples of what elements of the course developed these entrepreneurial skills. Binary data on students' perception of themselves as entrepreneurs or as individuals possessing entrepreneurial skills and data on whether a student's community sees them as entrepreneurs/someone possessing entrepreneurial skills were gathered to determine the impact of the course redesign on identity. These questions were paired with justifications for why students saw themselves in that light.

All qualitative data were refined in three stages. Once data was grouped as required, a paragraph containing all high-level topics discussed in the qualitative data was generated per grouping. The paragraph of high-level topics was then refined down to the most relevant themes based on the frequency of a topic being mentioned. If not displayed directly in theme form in tables, the themes were grouped as weighted by their frequency and used to describe higher—or lower-scoring groups in aggregate.

5. Results

Participants:

A total of 45 students undertook the improved curriculum. The demographic breakdown of the students in the course is featured in Table 1The majority of the students were between 20 and 23 years old, and approximately half were juniors and half were seniors. Twenty percent of respondents (9 of 45) were first-generation students. Almost all students (39) were from the Industrial and Systems Engineering department, with seven from other engineering departments.

Table 1: Demographic distribution of the manufacturing course being introduced to I&E resources

Demographic	Category	Count	Percentage
Gender	Male	34	75.6%
	Female	9	20.0%
	Prefer not to say	1	2.2%
	No Answer	1	2.2%
Ethnic Background	White (European descent)	18	40.0%
	Middle Eastern (Arab, Persian, West Asian descent, e.g., Afghan, Egyptian, Iranian, etc.)	10	22.2%
	Latino (Latin American, Hispanic descent)	7	15.6%
	Latino, White	3	6.7%
	East Asian, White	2	4.4%
	South Asian (South Asian descent, e.g., East Indian, Pakistani, Sri Lankan, Indo-Caribbean, etc.)	2	4.4%
	Southeast Asian (Filipino, Vietnamese, Cambodian, Thai, or other Southeast Asian descent)	1	2.2%
	No Answer	2	4.4%

The students' choice of projects varied widely. For example, one group made a clear bag that complied with clear bag policies at sporting events while also serving as a small step ladder for users who were of short stature. Another team worked on a small electronic device that could attach to a water bottle and estimate the amount of water a user drank each day. Another team worked on a more comfortable pillow for users who slept in different sleep positions.

We asked students about their Entrepreneurial identity to assess the extent to which they identified with entrepreneurial concepts. Table 2 summarizes bipolar ladder scores for five distinct questions related to entrepreneurial identity and the perceived usefulness of the class in growing students' identities and skills.

Students' ratings on their current tendency to take risks and be competitive (*Risk Rating*), showed a range of perspectives, with the majority giving moderately positive ratings. Positive ratings (scores of 3, 4, and 5) were primarily justified by students highlighting the role of risk-taking in growth, creativity, and confidence-building. They valued calculated risks in supportive environments like engineering projects, emphasizing self-belief, preparation, and the acceptance of failure as key drivers for willingness to take risks. Negative ratings (scores of -5 to -1) were less common and typically attributed to discomfort with uncertainty, a preference for guidelines, or a lack of confidence. Some students expressed a desire to take more risks but struggled with hesitation or internal barriers. The most frequent ratings were 2 and 3. These responses reflected a balanced approach to risk-taking, where students recognized its benefits but emphasized careful planning and linking risks to achievable rewards and personal development. These findings suggest that while many students appreciated the value of risk-taking, their willingness often depended on context and perceived support.

Students rated the impact of labs on their innovativeness and ability to execute innovative ideas as engineers (Innovativeness Rating) between -4 and 5. Positive ratings (scores of 3, 4, and 5) were most common, with students citing the labs' ability to reinforce foundational concepts, enhance tool/software proficiency, and provide hands-on training as reasons for their scores. Many noted that while the labs were interactive, engaging, and helpful for developing skills, there was limited flexibility for greater creative freedom or innovation. Students who gave the highest ratings appreciated the labs' balance between challenge and accessibility, which made them feel prepared to solve engineering problems. Negative ratings (scores of -4 to 0) were far less frequent and often tied to students feeling the labs were too rigid, overly step-based, or redundant with the knowledge they already possessed. A small number expressed frustration with a lack of alignment with personal goals.

The impact of in-class small group activities on students' innovativeness and ability to execute ideas (*Idea Execution Rating*) received mixed ratings, with the most frequent scores being 4 and 5, reflecting positive experiences. Students who gave high ratings (4 and 5) found engaging ways to collaborate, benefit from peer learning, and have the opportunity to practice relevant soft skills in a simulated professional environment. Moderate ratings (2 and 3), while still noting the activities were useful, also noted the potential for improved feedback and more structured innovation-focused exercises to better support idea execution. Negative ratings (scores of -5 to -1) generally reflected dissatisfaction with the activities. Students expressed preferences for individual assignments, cited a lack of impact on their skills, or reported difficulties in working effectively within groups.

The tours (*Tour Rating*) received mostly positive ratings, with a majority of students assigning scores of 4 or 5. Students with these ratings appreciated the engaging and informative nature of the tours, highlighting how the tours provided valuable insight into industry practices and broadened their understanding of industrial engineering. These experiences were seen as instrumental in fostering innovation by showcasing the breadth of real-world applications and inspiring new perspectives on problem-solving. Moderate ratings (2 and 3) reflected that while the tours were engaging and informative, their impact on fostering innovation was less pronounced. Negative ratings (-1 or 0) were rare and typically associated with students who were unable to attend tours. Some students noted that while the tours were insightful, they did not directly contribute to their innovativeness or ability to execute ideas.

Student ratings of how this class prepared them for senior design projects (*Senior Preparedness Rating*) were mixed, with the most common scores being 3, 5, 1, and 0. Positive ratings (4 and 5) highlighted the class's ability to emulate senior design processes through teamwork, the design process, and familiarity with CAD and CAM software. Students noted that the low-stakes NPD project helped them build relevant skills and confidence, making them feel prepared to contribute meaningfully to their senior design teams. Students with moderate ratings (2 and 3) said they learned some soft skills that might be useful and found certain elements, like GD&T, moderately helpful. However, they suggested the course could be improved to better align with senior design. Negative ratings (-5 to -1) were primarily from students taking the class concurrently with senior design. They expressed frustration over the added burden and believed the class would be more beneficial if taken earlier in their academic careers. Additionally, juniors who had not yet taken senior design (score 0) were unsure of the course's utility in preparing them for it.

Table 2: Structured bipolar ladder scores rating students' willingness to take risks, perceived innovativeness, confidence when executing ideas, perceived value of tours, and perceived value add to their senior capstone project as a result of this course.

Score	Risk Rating	Innovativeness Rating	Idea Execution Rating	Tour Rating	Senior Preparedness Rating
-5	1	0	1	0	2
-4	0	1	0	0	0
-3	1	0	2	0	0
-2	2	1	0	0	1
-1	1	2	5	1	1
0	0	1	1	4	6
1	3	3	4	3	6
2	10	9	6	3	4
3	11	9	4	3	10
4	9	11	13	9	5
5	5	7	8	15	7
No Response	2	1	1	7	3
Average	2.41	2.7	2.36	3.36	2.04

Note: ***Risk Rating*** *refers to students' self-assessed tendency to take risks and be competitive.* ***Innovativeness Rating*** *pertains to the perceived impact of class labs on enhancing creativity and the ability to execute innovative engineering ideas.* ***Idea Execution Rating*** *captures how in-class small group activities influenced students' capacity to develop and implement new concepts.* ***Tour Rating*** *reflects how educational tours shaped students' innovativeness and practical application skills.* ***Senior Design Preparedness*** *indicates how well the class prepared or complemented students' readiness for their senior design/capstone projects.*

Table 3 summarizes students' perceptions of their entrepreneurial identity and their community's view of them as entrepreneurs. The table categorizes students based on whether they self-identify as entrepreneurs and whether they believe their community sees them in the same light. Responses include insights into why students hold these perceptions, factors such as personal confidence, skills, experiences, and community recognition or lack thereof. This analysis sheds light on the interplay between self-perception and external validation in shaping entrepreneurial identity.

Table 3: Students' internal and external perception of their entrepreneurial ability/identity

Do you see yourself as an entrepreneur?	Does your community see you as an entrepreneur?	Why do I see myself as an entrepreneur? Or as possessing the skills to be one if I wanted to be?	Why do I think my community sees me as an entrepreneur? Or as possessing the skills to be one if you wanted to be?
Yes (N = 16, ~ 35.5%)	Yes	• Some students feel they've had an entrepreneurial mindset from an early age, spurred by personal passion or family role models. • Some do not want to work for someone else. Some are running small ventures, tinkering with personal projects. • A recurring theme is the desire to help or serve others through their entrepreneurial endeavors, channeling ideas into real-world impacts.	• Some students already run small ventures, which shape others' perceptions. Some highlight that others ask for their input and collaborate in business endeavors. Some emphasize how overcoming challenges has earned them the confidence of peers who believe in their potential to innovate. Some highlight skills gained through university courses, which their community recognizes and attributes to entrepreneurial potential.
Yes (N = 3, ~ 6.6%)	No	• Some feel confident in their intelligence and ability to work independently. • Some highlight strong innovation and risk-management skills, believing they can create or improve ideas while weighing risks against rewards.	• Some students in this group aren't outwardly passionate about entrepreneurship, so others don't see them that way. • Some are focused on college or a more conventional path.
No (N = 6, ~ 13.3%)	Yes	• Some students do not like to be the main go-to person or believe they aren't the smartest in the room, which makes them hesitant about entrepreneurship. • Some feel they lack the motivation required, though they acknowledge they might explore entrepreneurship in the future if circumstances change.	• Recognition based on their problem-solving capabilities and strong drive. • Some point to being innovative and self-directed, which contributes to their entrepreneurial image/brand. • Some express optimism about their future, citing internships and personal growth as clear indicators to their community of their entrepreneurial potential.
No (N = 19, ~ 42.2%)	No	• Some students feel they lack creativity, making entrepreneurship seem challenging. • Some do not enjoy tasks like paperwork or being a leader, discouraging them from pursuing this path. • Some have never had entrepreneurial experiences or haven't seriously considered it yet. Some mention needing more confidence, flexibility, or resilience to handle potential hardships—qualities they do not currently see in themselves.	• Some students in this group feel their community doesn't view them as entrepreneurs, often seeing them more as engineers or job-seekers. • Some cite their obvious lack of interest in risk-taking as a sign to their community that they would not make good entrepreneurs. • Some note that they've never had an opportunity to showcase their entrepreneurial skills, so the community hasn't recognized them in that light.
No Response (N = 1, ~ 2.2%)		-	-

The course was redesigned to introduce I&E resources and NPD to students. The majority of students (36/45) indicated that they developed their communication and collaboration skills through interactions with other team members, as shown in Table 4. Less than half of students (21/45) report being able to identify opportunities based on the designed course activities. Changes made to the course impacted the future preparedness of students and their ability to recognize potential opportunities.

Table 4: Perceived entrepreneurial skills gained from this course

Skill	N	Themes amongst examples provided by students on how skills were gained
Communication and Collaboration	36	Team projects, assignments, and presentations. Managing group dynamics and communication styles/constraints. Needing to defend an idea in debate or team meetings. Arriving at group consensus through active listening and idea integration.
Creativity and Innovation	33	The design of final projects required creativity and idea generation. Collaborative ideation when blending diverse ideas from a team. Exposure to tools like AutoCAD and Solidworks. Prototyping and problem-solving required out-of-the-box thinking. The project focus being on real-world applications.
Flexibility and Adaptability	29	Adapting to group work challenges such as scheduling. Adjusting to project design and requirement changes under time constraints. Problem-solving with limited resources and access to tools. Balancing team and individual needs. Navigating the iterative design process.
Critical Thinking and Problem Solving	26	Challenges from in-class activities and homework assignments. The iterative process of designing practical prototypes. Team activities fostering both individual and collective critical thinking. Assignments that connected classroom content to real-world problems, like demand. planning and prototype development.
Future Orientation	25	Tours and field trips gave students a glimpse into what they should prepare for. Experiencing the product design lifecycle and thinking about manufacturing or marketing their product. Exposure to emerging technologies and how they would interact with products Career-relevant skills on display, such as teamwork, manufacturing methods, and the use of industry-standard software. Connecting the classroom to a career due to the nature of the project.
Self-Reliance	25	Taking initiative in groups. Problem-solving under limited guidance or when missing resources. Self-directed learning.
Opportunity Recognition	21	Exposure to real-world business processes and niche markets via tours. Identifying market gaps being a part of the project. Guest speakers and class presentations. Through experiences such as analyzing manufacturing processes and tours.
Comfort Risk	23	Presentations and helped students step out of their comfort zones. Fixing design flaws under tight deadlines, and experimenting with tools like Solidworks fostered a willingness to take risks and learn through trial and error. Knowing they had a supportive team, built confidence. Guest speakers taught growth mindsets and reduced students' fear of failure. Activities like pitching new project ideas to peers and "investors" encouraged students to take creative risks and trust in their ideas.

6. Discussion

The integration of NPD and entrepreneurial education into manufacturing courses presents a replicable model for fostering innovation and practical skills in engineering programs. By connecting students to I&E resources, this initiative addresses gaps in existing curricula and prepares students to navigate the complexities of scaling ideas into viable products.

The results showed that students attributed many of their skills gained and even aspects that defined their entrepreneurial identity to the collaborative nature of the semester project. Presentations allowed students to build public speaking and idea-pitching experiences. The theory was also put into practice when doing market research.

We wanted to assess the entrepreneurial inclinations of students who completed an NPD project to see if this project was aligned with their interests and inclinations. Risk tolerance is often associated with entrepreneurial thinking, and when polled, students in the course demonstrated a low risk tolerance. While some students were very risk-averse, most tolerated some amount of risk. Those who identified as more risk tolerant understood that this was a crucial element of innovativeness and creativity, and those with light risk tolerance indicated they wished to grow their level of comfort. We believe the project has room to improve, but conveyed the importance of risk tolerance towards developing an entrepreneurial mindset.

When assessing how the labs, small group activities, and tours supported students to grow their innovativeness and idea execution, we found that tours and labs rated higher than small group activities. The tours were the highest rated, and most students who attended the tours found them insightful and engaging. Students mentioned that the understanding of industry gained from tours encouraged them to be more innovative and think more deeply about the product design process. Most students felt the labs allowed them to gain and practice relevant skills that had real-world applications, thus growing their confidence and ability to innovate in the future. Some students, however, criticized the labs for being too restrictive and not allowing for freedom of innovation during the course itself. Similarly, while many students valued the group activities for their emphasis on collaboration and professional skill-building, there is room for improvement in aligning the activities more closely with innovation and individual needs.

The consensus on the relevance of the course and the project to senior design was split. Perceptions of effectiveness seemed to depend on the academic standing of the student. Seniors who were already in senior design disliked the burden this course project added to their workload. Students who had not yet taken senior design believed the soft skills they built would aid them in senior design, while some others were more optimistic about having gained relevant skills. Students who believed the course was helpful cited their knowledge of modeling software and manufacturing processes, making them more secure in the role they will play on future senior design teams.

Implementing the project has helped us identify some lessons learned and areas for future development. We found that embedding entrepreneurial components in a third-year class may be too late in the curriculum, and more focus early in the curriculum may be more effective. Based on student feedback, the incorporation of mentorship and real-world examples was crucial in bridging the gap between academic learning and industry practices, and we hope to emphasize this more in future semesters. We hope to expand the course redesign model to other engineering disciplines in the future, leveraging shared resources developed through this project. Additionally, we hope to explore entrepreneurial education's long-term impact on participating students' career outcomes through longitudinal surveys or follow-up with students after graduation.

Some limitations of our evaluation of this course update include (i) the lack of a control group to compare students who worked on entrepreneurial projects versus the original course structure, (ii) not having baseline data to make comparisons longitudinally in terms of student identity development, and (iii) the variability in project complexity due to the nature of product development. While (iii) is difficult to overcome given the nature of NPD, (i) and (ii) can be addressed by studying parallel courses in manufacturing and by introducing a baseline assessment at the beginning of each course to assess entrepreneurial identity development.

7. Conclusion

The redesigned course provides a roadmap for integrating entrepreneurial thinking into manufacturing education. Students were successful at designing and prototyping innovative solutions to problems in their lives while also applying manufacturing-relevant skills such as manufacturing process selection, cost estimation, and making and interpreting engineering drawings. Incorporating speakers and providing opportunities for tours of local manufacturing businesses also allowed students to understand the connections between business and technical considerations in manufacturing. By fostering a culture of innovation, connecting students to practical resources, and emphasizing inclusivity, this initiative has the potential to produce entrepreneurial engineers ready to tackle real-world challenges.

8. References

Bielefeldt, A. R., Polmear, M., Knight, D., Swan, C., & Canney, N. (2018). Intersections between Engineering Ethics and Diversity Issues in Engineering Education. *Journal of Professional Issues in Engineering Education and Practice*, *144*(2), 04017017. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000360

Cardon, M. S., Gregoire, D. A., Stevens, C. E., & Patel, P. C. (2013). Measuring entrepreneurial passion: Conceptual foundations and scale validation. *Journal of Business Venturing*, *28*(3), 373–396. https://doi.org/10.1016/j.jbusvent.2012.03.003

Cox, D. (2017). Development of Hands-on Laboratory Resources for Manufacturing Engineering. *Annual Conference and Exposition*. American Society for Engineering Education.

Da Silva, G., De Barros, M., & Costa, H. (2015). Entrepreneurship in Engineering Education: A Literature Review. *International Journal of Engineering Education*, *31*(6A), 1701–1710.

Fang, N. (2011). *Integrating Entrepreneurship into Manufacturing Engineering Education*. 22.905.1-22.905.13. https://peer.asee.org/integrating-entrepreneurship-into-manufacturing-engineering-education

Franke, N., & Lüthje, C. (2004). Entrepreneurial intentions of business students—A benchmarking study. *International Journal of Innovation and Technology Management*, *01*(03), 269–288. https://doi.org/10.1142/S0219877004000209

Mohammed, J. (2021, July 26). *Introducing Entrepreneurship and Innovation in a Manufacturing Design Course*. 2021 ASEE Virtual Annual Conference Content Access. https://peer.asee.org/introducing-entrepreneurship-and-innovation-in-a-manufacturing-design-course

Osta, A. (2023, June 25). *Introducing Entrepreneurship in Manufacturing courses: A Hands-on Project approach*. 2023 ASEE Annual Conference & Exposition. https://peer.asee.org/introducing-entrepreneurship-in-manufacturing-courses-a-hands-on-project-approach

Pifarré, M., Sorribas, X., & Villegas, E. (2009). BLA (Bipolar Laddering) Applied to YouTube. Performing Postmodern Psychology Paradigms in User Experience Field. In *Advanced Technologies* (pp. 952–958). InTech. https://doi.org/10.5772/8233

Pifarré, M., & Tomico, O. (2007). Bipolar laddering (BLA): A participatory subjective exploration method on user experience. *Proceedings of the 2007 Conference on Designing for User eXperiences, DUX'07*. https://doi.org/10.1145/1389908.1389911

Ssemakula, M. (2002). Introducing Hands On Manufacturing Experience To Students. *Annual Conference and Exposition*. ASEE.

Watson, J., Vondra, F., & Fidan, I. (2017, June 24). *The Development of a Framework for 3D Printing, Casting, and Entrepreneurship*. 2017 ASEE Annual Conference & Exposition. https://peer.asee.org/the-development-of-a-framework-for-3d-printing-casting-and-entrepreneurship

Yu, W., Zheng, Z., & He, J. (2024). Integrating Entrepreneurial Education into STEM Education: *Research in Science Education*. https://doi.org/10.1007/s11165-024-10193-2

Appendix

Appendix A: Student Survey Instrument

Section 1: Demographic Information

1. Current Level of Education
   Options: Freshman, Sophomore, Junior, Senior, Graduate.

2. Department
   Response: Open-text field.

Section 2: Self-Assessment of Entrepreneurial Skills

Each question in this section required a rating of positivity or negativity accompanied by a qualitative response contextualizing the rating.

3. Rate your current tendency to take risks and be competitive.
   Scale: -5 (Strong Negative Feeling) to +5 (Strong Positive Feeling).

4. Rate how the labs in this class have impacted your innovativeness and ability to execute innovative ideas.
   Scale: -5 (Strong Negative Feeling) to +5 (Strong Positive Feeling).

5. Rate how the in-class group activities have impacted your innovativeness and ability to execute innovative ideas.
   Scale: -5 (Strong Negative Feeling) to +5 (Strong Positive Feeling).

6. Rate how class tours have impacted your ability to innovate and execute ideas as an engineer.
   Scale: -5 (Strong Negative Feeling) to +5 (Strong Positive Feeling).

7. Rate how well the course prepared you for, or complemented, your senior design or capstone project.
   Scale: -5 (Strong Negative Feeling) to +5 (Strong Positive Feeling).

Section 3: Skills Development

8. Which of the following skills do you feel this course helped you gain or develop? Select all that apply:

   - Initiative and Self-Reliance.
   - Flexibility and Adaptability.
   - Communication and Collaboration.
   - Creativity and Innovation.
   - Future Orientation.
   - Critical Thinking and Problem Solving.
   - Opportunity Recognition.
   - Comfort with Risk.

9. Follow-up for Selected Skills
   For each selected skill, participants were asked to give an example of how the course helped develop that skill.
   Response: Open-text field.

Section 4: Entrepreneurial Identity

10. Do you see yourself as an entrepreneur or possessing the skills to become one?
    Options: Yes, No.

11. Explain why or why not, using examples from your personal or course experience.
    Response: Open-text field.

12. Do you think your community (family, peers, etc.) sees you as an entrepreneur?
    Options: Yes, No.

13. Explain why or why not, using examples from your interactions.
    Response: Open-text field.

Section 5: Perceptions of Entrepreneurial Behaviors

14. Rate the following statements:
    Scale: Strongly Agree, Somewhat Agree, Neither Agree nor Disagree, Somewhat Disagree, Strongly Disagree.

    - *When working in a group, I ensure everyone participates.*
    - *I can change plans quickly and effectively when needed.*
    - *I enjoy solving problems and thinking of new ideas.*
    - *I investigate both sides of an argument.*
    - *I like having a backup plan in case my original plan doesn’t work.*

Appendix B: Full Table of Skills Gained

Skill	N	Themes Fixed
Self Reliance	25	**Independent Work on Tasks**: Many students emphasized gaining self-reliance through individual work on labs, assignments, and projects. This included instances where they had to learn or complete tasks without direct guidance. **Taking Initiative in Groups**: A recurring theme was stepping up to lead group projects or volunteering for tasks when others were less active. This fostered confidence and a sense of responsibility. **Problem-Solving Under Limited Guidance**: Students frequently mentioned developing self-reliance by addressing gaps in provided resources, pushing them to research, learn independently, and find unique solutions. **Overcoming Group Challenges**: When faced with uncooperative or absent teammates, students often adapted by taking on additional responsibilities, emphasizing resilience and adaptability. **Self-Directed Learning**: Some students highlighted using supplementary resources like online videos to deepen their understanding, demonstrating their ability to take ownership of their learning process.
Flexibility and Adaptability	29	**Adapting to Group Work Challenges**: Many students emphasized adapting to scheduling conflicts, group member absences, and unexpected difficulties during presentations. They highlighted learning flexibility in coordinating and contributing under changing circumstances. **Adjusting to Project Changes**: Flexibility was developed through last-minute adjustments to project designs, specifications, and materials, teaching students how to pivot quickly and efficiently to meet deadlines. **Problem-Solving Without Resources**: Students learned to adapt by finding creative solutions to problems like working with limited hardware or incomplete materials in labs and projects. **Balancing Team and Individual Needs**: Managing personal constraints, like work schedules, while meeting team commitments helped students exercise adaptability. **Iterative Design Process**: The design and prototyping phases of projects required constant adjustments and open-mindedness, reinforcing adaptability in problem-solving.
Communication and Collaboration	36	**Team Projects and Presentations**: Many students emphasized the importance of group projects, class assignments, and presentations in developing their communication and collaboration skills. **Group Dynamics and Teamwork**: Working within diverse teams, including virtual collaboration with remote members, helped students adapt their communication styles to different group dynamics and ensure inclusivity. **Real-World Applications**: Experiences such as tours, debates, and engineering design projects enhanced their ability to articulate ideas, discuss technical concepts, and collaborate on complex tasks. **Problem-Solving in Groups**: Resolving issues like scheduling conflicts, deciding on project directions, and ensuring clarity during group meetings strengthened their collaborative skills. **Active Listening and Idea Integration**: Students learned to balance their own ideas with others, fostering a collaborative environment where all voices were heard and integrated into the final outcomes.

Creativity and Innovation	33	**Design and Final Projects**: The design and final projects were frequently cited as key opportunities to foster creativity, allowing students to brainstorm, develop prototypes, and innovate solutions tailored to real-world needs. **Collaborative Ideation**: Group work facilitated the blending of diverse ideas, enabling students to collaborate on creative concepts and combine them into practical outcomes. **Practical Tools and Methods**: Tools like AutoCAD and SolidWorks, along with exposure to different design methods, helped students explore innovative ways to solve problems and expand their creative potential. **Prototyping and Problem-Solving**: Tasks like creating prototypes and designing products with unconventional materials encouraged students to think outside the box and focus on market-driven innovation. **Focus on Real-World Applications**: Projects emphasized addressing real-world challenges, pushing students to innovate by observing daily needs and translating them into feasible solutions.
Future Orientation	25	**Tours and Field Trips**: Industrial tours and field trips were pivotal in helping students envision potential career paths. These experiences highlighted industry roles and helped clarify personal interests and goals. **Project-Based Learning**: Design projects and product creation activities helped students think ahead by applying skills to real-world scenarios, fostering a forward-looking mindset. **Exposure to Emerging Technologies**: Lectures and discussions on emerging technologies, such as robotics and factory automation, encouraged students to consider future trends in their fields. **Career-Relevant Skills**: Students recognized how teamwork, manufacturing methods, and the use of industry-standard software (e.g., SolidWorks) prepared them for future roles. **Connecting Classroom to Career**: Many students appreciated how the course bridged academic theory with practical, career-relevant skills, motivating them to pursue related engineering paths.
Critical Thinking and Problem Solving	26	**In-Class Activities and Assignments**: Students frequently highlighted the role of in-class problems, labs, homework, and exams in cultivating critical thinking by encouraging them to apply learned concepts to solve challenges. **Design and Final Project**s: The iterative process of designing prototypes and addressing flaws in product designs helped students develop problem-solving skills by requiring rapid adaptations and creative solutions. **Software and Technical Tools**: Using tools like SolidWorks and AutoCAD pushed students to solve technical problems, such as creating innovative designs or overcoming challenges related to software usage. **Teamwork in Complex Tasks**: Group projects and collaborative assignments provided opportunities to address unexpected challenges, fostering both individual and collective critical thinking. **Real-World Application**: Assignments that connected classroom content to real-world problems, like demand planning and prototype development, emphasized practical problem-solving skills.
Opportunity Recognition	21	**Tours and Field Trips**: Industrial tours and field trips exposed students to real-world business processes and niche markets, helping them identify potential opportunities in their fields. **Design and Term Projects**: Working on projects required students to identify market gaps, develop solutions, and recognize how their designs could solve real-world problems. **Guest Speakers and Class Presentations**: Guest speakers provided insights into recognizing market needs, consumer behavior, and entrepreneurship opportunities, which inspired students to think about untapped potential. **Real-World Application**: Experiences such as analyzing manufacturing processes or

		case studies helped students understand how to spot opportunities within industry trends.
Comfort Risk	23	**Presentations and Public Speaking**: Many students mentioned that presenting in front of the class helped them step out of their comfort zones and become more comfortable with taking risks. **Prototype Development and Experimentation**: Tasks like manufacturing prototypes, fixing design flaws under tight deadlines, and experimenting with tools like SolidWorks fostered a willingness to take risks and learn through trial and error. **Supportive Team Environment**: Collaborative projects allowed students to take risks, knowing they had a supportive team to back them up, which built confidence and resilience. **Exposure to Failure and Growth Mindset**: Guest speakers and real-world lessons on failure taught students to embrace risks as part of learning and growth, reducing their fear of failure. **Novel Ideas and Innovation**: Activities like pitching new project ideas to peers and "investors" encouraged students to take creative risks and trust in their ideas, even in uncertain situations.