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Fostering Entrepreneurial Mindset via Hands-On Learning: A Case Study on Project-Based Learning in Advanced Manufacturing and Additive Manufacturing Courses

Dr. Anu R Osta, Rowan University

Dr Anu Osta is an Associate Teaching Professor in Mechanical Engineering Department at Rowan University. His teaching interests are Engineering Mechanics, Materials Science, Manufacturing, and Design.

Dr. Behrad Koohbor, Rowan University

Behrad Koohbor is an Assistant Professor of Mechanical Engineering at Rowan University.

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1. Introduction

Advanced manufacturing integrates cutting-edge technologies such as robotics, artificial intelligence (AI), Internet of Things (IoT), and Additive Manufacturing. Advanced manufacturing technologies are fundamental to Industry 4.0. Educating students in these areas is crucial to developing a workforce capable of innovating and managing highly automated manufacturing systems. Modern manufacturing systems require interdisciplinary knowledge spanning mechanical, electrical, software, and systems engineering. Therefore, teaching methods for modern manufacturing should emphasize creative thinking in process design and production. 3D printing, for example, empowers engineers to design and produce components previously impossible with traditional methods, unlocking new avenues for innovation. Advanced manufacturing concepts bridge the gap between academic theory and real-world application. Students gain exposure to technologies and practices actively used in the industry, such as CAD/CAM software, digital twins, and data-driven decision-making. It also involves teaching about sustainable practices, such as minimizing waste through precision machining, optimizing resource usage via automation, and leveraging smart or recycled materials. Advanced manufacturing techniques, such as mass customization and flexible manufacturing systems, enable consumers to obtain products tailored to their specific needs. Incorporating advanced manufacturing education within engineering curricula prepares students for the technology-driven modern industrialized world.

2. Literature Background

There is quite a lot of literature available on how to design teaching materials on Advanced Manufacturing and deliver them effectively. Felder and Brent[1] discuss how to design engineering curriculum and assessment strategies so that they align with ABET's student outcomes, program educational objectives, and program outcomes. Prince and Felder[2] reviewed inductive teaching methods, including project-based and problem-based learning, and discussed their effectiveness in engineering education. Kolodner[3] discussed the case-based reasoning in science education where students learn by solving design-and-build challenges that mirror the practices of scientists and engineers. Ngaile[4] highlighted the pedagogical challenges in teaching modern manufacturing concepts. To address these challenges, a study was conducted in which the students across three institutions worked together on projects related to advanced manufacturing technologies. The impact of the course was assessed through pre- and post-surveys conducted by an external evaluator. The study emphasized the importance of effective communication platforms and guidelines for successful multi-institutional collaborations. Megri[5] describes a virtual summer camp focused on advanced manufacturing and 3D printing for high school and early-college STEM students. The key takeaway was that including hands-on projects (like designing tool holders and playground equipment), interactive activities (like using a sputter coater), and guest lectures from industry experts resulted in positive student outcomes with significant gains in manufacturing knowledge, communication skills, and an interest in pursuing further manufacturing related studies and careers. Hart[6] describes some advancements in manufacturing processes, specifically focusing on the integration of new technologies and methodologies to enhance efficiency and productivity in manufacturing settings. They include case studies that illustrate successful implementations of these technologies and also address future trends in manufacturing, emphasizing the need for continuous innovation and adaptation to remain competitive in a rapidly evolving industry. Go[7] describes a 14-week project based advanced manufacturing course at MIT, teaching product design, and AM processes. This led to innovative prototypes, patents, and further product research. They also made several recommendations for future implementations such as clarifying project goals early in the semester, to control the scope of work while maintaining high ambitions. Salah[8] examined the use of virtual reality in teaching advanced manufacturing to improve sustainability and prepare students for Industry 4.0 challenges. A number of textbooks[9,10,11,12] serve as excellent resources for teaching Advanced and Additive Manufacturing.

Engineering entrepreneurship education is crucial for several reasons. It develops essential skills like critical thinking, problem-solving, creativity, teamwork, communication, leadership, and risk-taking. By exposing students to the process of identifying opportunities, developing solutions, and bringing them to market, an entrepreneurship mindset encourages innovation and the development of new technologies and businesses. By encouraging students to apply their engineering knowledge to address real-world problems, such as climate change, healthcare, and poverty, engineering entrepreneurship education can contribute to a more sustainable and equitable future. The role of entrepreneurship in engineering education, emphasizing the development of an entrepreneurial mindset to enhance innovation has been explored by Byers[13], Neck[14] and many others. Bossman[15] cites the necessity of embedding entrepreneurial mindsets in engineering education and discusses how equipping engineers with an entrepreneurial perspective enhances their ability to address real-world challenges effectively. João[16] and Zappe[17] investigate instructional strategies and evaluation methods to instill an entrepreneurial mindset in engineering students such as project-based learning.

In this paper, we discuss project-based approaches to instilling the entrepreneurial mindset. The courses discussed are the Advanced Manufacturing and the Additive Manufacturing and Characterization. These courses are offered at both the undergraduate and graduate levels at Rowan University (RU). Typical enrollments are between 30-40 students per course. The courses are offered as in-person electives in the Fall semester with 2 lecture sessions per week. The catalogue descriptions and the syllabus of these courses are as follows

Catalogue description of Advanced Manufacturing

This course will provide students with knowledge of modern manufacturing processes, how design is optimized for manufacture, and information on future directions of manufacturing, such as additive (3D printing) manufacturing techniques and the use of digital data across the product life cycle. The course will also discuss the taxonomy of manufacturing processes and provide an examination of current state of the art manufacturing with an emphasis on trends and directions in manufacturing, the relationship of digital data to design and production, and the impact of supply chain on production decisions.

List of topics covered in Advanced Manufacturing include High Speed Machining, Abrasive Jet Machining, Water Jet machining, Ultrasonic Machining, Electro Discharge, Laser Beam, Plasma Beam, Ion Beam Machining processes, Chemical Milling Processes, Biomedical Manufacturing, Spray Technologies, Additive Manufacturing, Quality Control and Lean, and Automation (Robotic Manipulator, CNC).

Catalogue description of Additive Manufacturing and Characterization

This course covers topics related to the fundamental concepts of additive manufacturing (AM) and materials characterization. The first 60% of the class focuses on the introduction and basic *principles of additive manufacturing, including but not limited to AM of polymeric, ceramic, and metallic parts. Topics such as ink-based direct writing, laser-assisted additive manufacturing, thermal spray, and hybrid AM technologies will be discussed. The second part of the class covers topics on a variety of techniques used to characterize the structure and composition of engineering materials, including metals, ceramics, polymers, and composites with a special focus on structures fabricated by AM. The emphasis will be on microstructural characterization techniques, including optical and electron microscopy as well as X-ray diffraction techniques. Topics related to the novel mechanical characterization techniques will be discussed briefly. Real-world examples of materials characterization will be presented throughout the course, including microstructural, mechanical, and failure characterization of additive manufactured structures.*

3. Methodology

Entrepreneurship based project components were implemented in both the courses during the Fall 2024 semester. The projects contributed 10% and 30% towards the final grade in Advanced Manufacturing and Additive Manufacturing courses, respectively. We will discuss in the following sections, the projects designed, the impact they created on the students' learning successes and the student feedback on this approach.

3.1 Project - Conveyor System Modeling and Manufacturing (Advanced Manufacturing)

Material handling plays a crucial role in manufacturing by ensuring the efficient movement, storage, and control of materials throughout the production process. It is the process of moving, storing, and controlling materials and products throughout the manufacturing process. Conveyor systems are essential components of material handling and are used for moving raw materials, inventory, and finished products throughout the facilities and warehouses. This class project required the students to team up as 3 membered groups and design, manufacture, and demonstrate a simplified conveyor system. The basic conveyor design consisted of two rollers connected by a spur gear mechanism to transfer the rotary motion, one serving as the driver roller and the other one serving as the driven roller. The driver roller was driven by a stepper motor powered by a 9V battery, which providing both speed and directional motion control. An Arduino Nano microcontroller was to be programmed to control the stepper motor's operation.

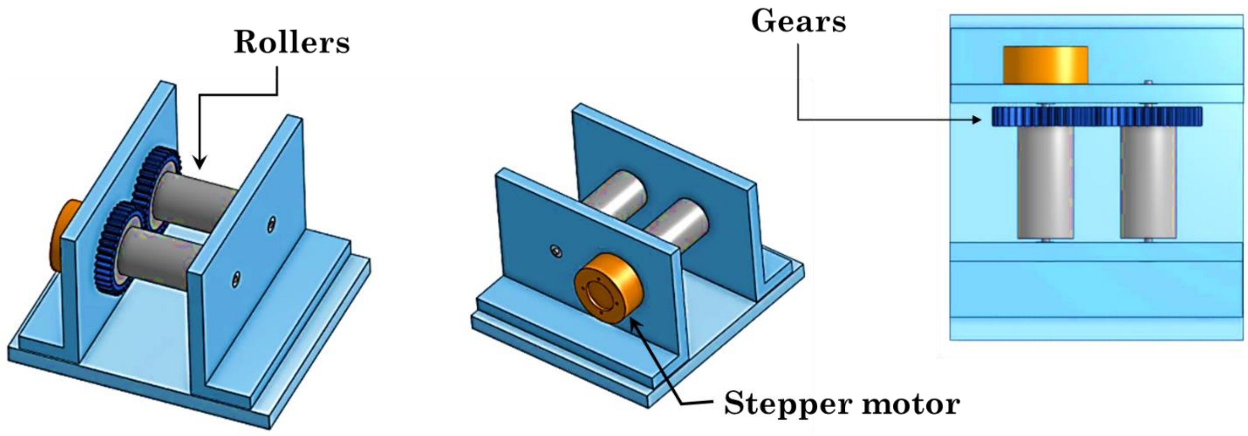

Figure 1. A CAD view of the conveyor

A stepper motor driver interfaced between the Arduino and the stepper motor, enabling control of direction and speed. The wiring between the driver, switches and power supply was implemented on a PCB board and it comprised the control panel. The control panel had 4 buttons labeled for achieving the following:

On-Off button: This would start the motor or shut it off when pressed

Forward/Reverse direction button: This would rotate the stepper motor clockwise or counterclockwise initiates forward or reverse rotation of the conveyor belt.

Speed Increase button: This would increases speed of rotation of the stepper motor.

Speed Decrease button: This would decreases speed of rotation of the stepper motor.

A sample control panel design is shown below.

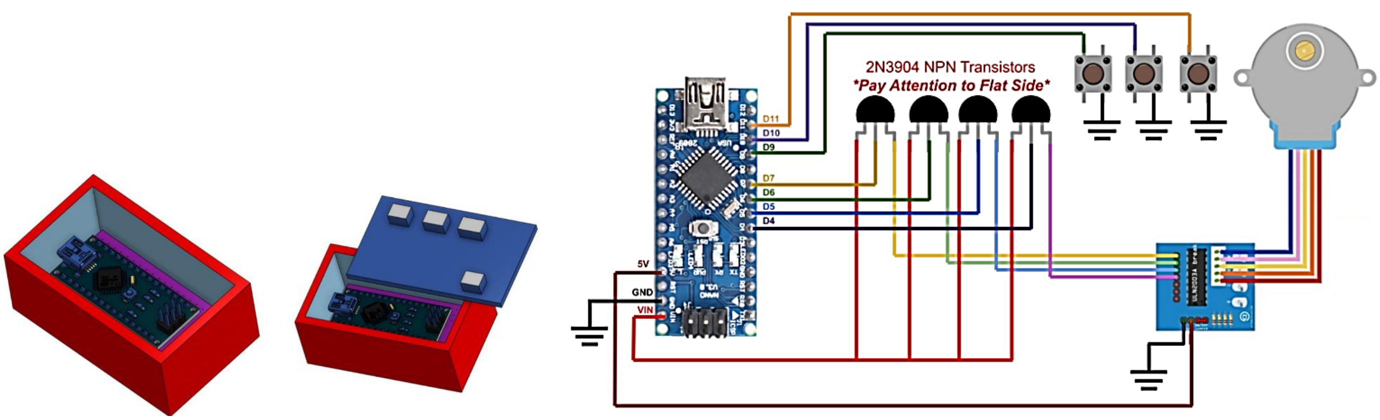

Figure 2. A CAD representation of the control panel (left) and the circuit diagram (right)

The learning objectives for this project component were as follows: (1) To enable students to develop a mechanical design of a manufacturing system- During the design process the students would learn how to model the physical components of a conveyor system, calculate gear ratios and roller rotation and belt translation speeds. Each student team was expected to develop their individual product designs independently. The teams were given the option to use a standard modeling software like Solidworks, Autodesk or Onshape. (2) To enable students to get skilled in electronics integration – wiring, soldering and interfacing electronic components, such as the Arduino, stepper motor driver, transistors, switches and the power supply helped the students acquire electronics integration skills, (3) To help students learn Arduino Programming - students gained hands-on experience programming an Arduino Nano inorder to control the stepper motor, learning how to implement direction changes and variable speed control, (4) To help students learn Manufacturing – the conveyor components were 3D printed using FDM and then assembled. (4) To help students understand System Testing and Optimization - by testing their models, students were able to analyze the performance of their conveyor system and make adjustments to optimize its efficiency. Besides the above the students were encouraged to consult online resources like Youtube, Instructables, Hackster, IONOS, etc. The circuit diagram was shared as a part of instructions and guidelines. A sample circuit diagram is given below.

Each team was required to present their projects by demonstrating its function to the class in person. Each team was also asked to upload a short project report as well as their CAD files as SLDPRT, SLDASM or STEP file formats. The grading rubric on the hands-on portion evaluated the following criteria

(a) Mechanical Design: Detailed, well-thought-out CAD models; all components (rollers, gears, motor, control panel) are accurately modeled. CAD files submitted in correct formats.
(b) Control Panel Design & Layout: Control panel is neatly designed, labeled, and integrated well with the conveyor system or independently connected. Button layout is intuitive and responsive. Professional wiring and component placement.
(c) Electronics Integration: All components (Arduino, motor, driver, power supply) are correctly wired and soldered with clean, safe connections. Breadboard and PCB are neatly arranged. Excellent understanding of circuitry shown.
(d) Programming & Functionality: Arduino code is well-structured, fully functional, and includes clear comments. System responds perfectly to all control panel functions (on/off, speed control, direction). Demonstrated professional understanding of motion control.

The final report aimed to assess the level of success achieved through student perceptions of the Business mindset, ABET criteria fulfillment, and the Entrepreneurial mindset by analyzing responses to a set of questions. The detailed questions are mentioned below.

3C's of Entrepreneurial Mindset

Curiosity:

- On a scale of 1 to 5, how often did you actively seek out new knowledge or techniques to improve your project?
  1 – Never 2 – Rarely 3 – Sometimes 4 – Often 5 – Always
- How did curiosity about the subject help you in addressing project challenges? (Open-ended)

Creating Value:

- On a scale of 1 to 5, how would you rate the creativity of your solution in the project design?
  1 - Not creative at all 2 - Minimally creative 3 - Moderately creative
  4 - Highly creative 5 - Extremely creative
- Provide an example of a creative idea or solution you used in your project. (Open-ended)

Connections:

- How well did your team collaborate to achieve the project goals?
  1 – Poorly 2 - Below average 3 – Average 4 – Good 5 – Excellent
- How well did your team function in terms of assigning roles, responsibilities, and working together? 1 – Poorly 2 - Below average 3 – Average 4 – Good 5 – Excellent
- Describe a challenge your team faced during collaboration and how you overcame it. What did you learn about teamwork in this project? (Open-ended response)

ABET Criteria Fulfillment

Problem Solving:

- How effective was your team in identifying and solving the technical problems encountered during the project? 1 – Ineffective 2 - Slightly effective 3 - Moderately effective 4 - Very effective 5 - Extremely effective
- Describe a significant problem your team encountered and how you solved

Application of Engineering Principles:

- On a scale of 1 to 5, how well did you apply engineering principles to design and implement your project?
  1 – Poorly 2 - Below average 3 – Average 4 – Good 5 – Excellent
- Which engineering concepts were most helpful in your project? (Open-ended response)

Business Model Canvas Application

Value Proposition:

- How effectively did your project address a real need or provide value to a target consumer?
  1 - Not effective 2 - Slightly effective 3 - Moderately effective 4 - Very effective

5 - Extremely effective

- What value does your project provide, and to whom? Who are the potential users or beneficiaries of your project? (Open-ended response)

Revenue Streams/Cost Structure:

- Did your team consider the financial aspect of your project, such as potential costs and revenues? Yes/No
- Briefly develop a cost structure for your project.

Final Reflection:

- What were the most significant lessons you learned from this project? (Open-ended response)

3.2 Project – Design and Fabricate an S-Binder with Additive Manufacturing for Maximum Strength-to-Weight Ratios (Additive Manufacturing)

The objective of this project was to design and additively manufacture a plastic S-binder for maximum strength-to-weight ratios. The S-binder geometries would be the same as a commercially available counterpart. Price, mechanical, and other geometric details of the commercially available part could be found from the McMaster-Carr website (item No. 6043T43). The commercial part is made of an unspecified polymer and the part is rated for 50 lbs load bearing capacity. The entire class population was divided into several groups of 4. The groups were allowed to form naturally among friends and peers. Several groups included both female and male students.

The learning objectives included (1) a literature survey to identify the most significant design and manufacturing criteria that affect the properties of the final product, (2) consideration, calculation, and comparison of the cost between the designed prototype and the commercially available part, and (3) to establish a team effort to design, fabricate, test, and interpret the testing results required for launching a new product made with Additive Manufacturing. Each team was instructed to identify the most critical design criteria that affect the mechanical load-bearing capacity of the final product. For instance, print direction and post-printing heat treatment were among the two most identified technical aspects of the design. Upon the identification of the optimal design details, each group was tasked to fabricate two identical parts for end-of-semester testing. Inspired by the Student Bridge Contest at SAMPE, an internal competition was held in the second to last session of the class. This competition was held in the Mechanical Engineering labs where teams tested their prototypes for maximum tensile load before fracture and structural weight. Similar tests were also performed on the commercial part. The group in charge of designing the prototypes with the highest strength-to-weight ratio was recognized. All groups used their mechanical test results and observations made therein in a final 15-minute presentation. All students were also required to submit a final report similar to the one for the Advanced Manufacturing project. This report included the same questions and examined the same indicators as those outlined earlier for the Advanced Manufacturing course.

In addition to all in-class project activities described above, a unique aspect of this course is that the instructor invites (once or twice per semester) an external expert from the industry to discuss with the class the real-world applications of AM. The insights gained through these conversations could be implemented in the final project.

Figure 3 – Pictures showing different activities during Additive Manufacturing project: (A) In-lab testing of S-binder prototypes with a topology-optimized S-binder shown in (B). (C) The results of lab testing are written on the lab white board in real time. (D) Students present their design and manufacturing approach to their peers during the last day of the class.

4. Discussions

In this section we will discuss the responses to some of the class project report submissions. We first present the responses to the Conveyor Project and then follow-up with those of S-binder.

Responses to the Conveyor Project

How did curiosity about the subject help you in addressing project challenges?
Working with a stepper motor was new for most team members, so learning how it worked and how to code it was the most interesting.
We were curious about how the gear was going to fit and work in regards to how to model the gears, how many gears we would need, and how to actually fit the gears in the body of the conveyor.
When it came to programming the stepper motor, new knowledge was pursued in order to complete our work. It was out of a need to create good code, remembering and reinforcing skills that had become rusty, and a curiosity to improve the quality of said code that online resources were utilized and referenced. While the code that is presented here is better than it would have been without prior research, there are aspects that could be implemented for the future that would elevate its quality even further, such as adding debouncing on the buttons and other things. Many adjustments to the conveyor belt itself had to be redesigned for innovation and efficiency, as well.
Curiosity about the subject played a big role in helping us tackle project challenges. Because we were new to coding and design, our curiosity drove us to explore various resources and learn more. We spent time researching online, watching tutorials, and asking questions, which helped us understand complex parts of the project step-by-step. Our curiosity also motivated us to try different methods and experiment with new ideas rather than just following basic instructions. This helped us solve issues creatively, especially when we ran into problems with coding and button functions. Curiosity kept us engaged, helped us stay positive, and ultimately led us to find solutions that we might not have considered otherwise.
Our interest in advanced manufacturing and 3D printing led us to research how gears work, how gears can be printed accurately using 3D printing, and how electronics such as the Arduino Nano and stepper motor could be incorporated. Through trial and error and studying different aspects of the product including the gears, the materials used, and the motor control, we were able to identify ways to enhance the performance of the prototype. This curiosity helped us to keep on improving the system and the gears' movement, which in turn improved the performance of the system.
Our group's curiosity about Advanced Manufacturing helped a lot with the Conveyor System Modeling and Manufacturing project. It made us want to learn more about different manufacturing methods, materials and technologies not just in theory but in a practical way. This helped us find useful techniques and tools like SolidWorks which made the design more accurate and efficient. We learned new technology on how to print and operate 3D printing machines with the help of Cura software. Our curiosity also led us to look into real-world conveyor systems and automation trends. So, we could solve problems with new ideas, making the system stronger and smoother. Our curiosity pushed us to move beyond basic requirements, constantly seeking better solutions and refining the system.

Provide an example of a creative idea or solution you used in your project.
In order to make the entire assembly more compact, we used a third small gear that was offset from the two bigger gears. This idea made the gears more compact, rather than making them in a line which would increase the size of the conveyor.
We were having a hard time with fitting the gears into their respective places in the bearings and came up with a creative solution to have the pegs detachable. This made it so we could actually fit the gear in place without having the body of the project be in two pieces.
The design of our rollers were remade to have the shaft fit into the bearings and the rollers themselves be separate parts for easier assembly. Having them be separate parts reduced the complexity of the design during printing. This allowed for extra time to be dedicated towards testing and further revisionary work on the project.

One creative solution we used in our project was designing a custom button layout for the control interface. Initially, we struggled with standard button functions for controlling the conveyor system, as they didn't fully meet our needs. Instead of sticking with the basic setup, we experimented with different button placements and functions until we created a layout that was both intuitive and effective. And example is all similar kind of buttons with Numbering 1,2 and 3
One of the creative solutions that we employed was the use of idler gears to make sure that all the gears were rotating in the same direction. First, we encountered problems with the correct rotation alignment with a basic gear train. After conducting research and brainstorming, we concluded that if an extra gear is placed between two main gears, the direction of rotation can be changed, and all gears can rotate in the same direction.
We only used jumper wires for soldering. Later we realized how effective 22AWG wires are for soldering the circuit on PCB proto-board. We can cut and use any 22AWG length wires which enhance the circuit's overall stability. They are easy to cut and bend into precise angles, creating a professional appearance on the proto-board. Switching to 22AWG wires improves the quality, durability and reliability of soldered circuits, reducing the risk of broken connections.

Describe a challenge your team faced during collaboration and how you overcame it. What did you learn about teamwork in this project?
At times it was difficult to arrange times to meet based on our busy schedules, but we decided at times to do work and meetings with only some of the team present. We would then communicate our progress and keep the team up to date on new breakthroughs.
A challenge our team faced was finding a time to meet up with all of our different schedules. Rather than trying to have everyone meet up at the same time, we divided the work prior and arranged for specific people to do predetermined tasks. We learned how to manage schedule differences between group members and expanded our knowledge on teamwork in general.
One of our Solidworks versions was not up to date, so the files to the parts and assembly were transferred and completed by another team member. Constant communication and collaboration enabled the team to complete the work on the conveyor belt 3D model.
During our project, our team faced a challenge: deciding on the best approach for the 3D design and coding aspects. Each team member had different ideas, making settling on a single direction difficult. To overcome this, we took time to discuss everyone's ideas and find a way to combine the best parts of each. We also used resources like YouTube tutorials and asked our professor for guidance, which helped us learn new techniques and improve our design. Ultimately, this experience taught me that teamwork is about listening to each other, being open to different ideas, and using available resources when facing challenges. It showed me that collaboration and using outside help can make a big difference in achieving a project's goals.
One of the main issues that we encountered was the distribution of the work concerning mechanical and electronic parts. Some of the team members were more experienced in mechanical design while others were more experienced in electronics and programming. This resulted in some confusion in the initial phases of the project about how the mechanical and electrical systems would interface. To address this, we enhanced our communication by scheduling meetings in which each team member reported progress and how his/her contribution impacted the overall system. From this, we understood that teamwork is all about communication, understanding of each other's roles and responsibilities, and a willingness to coordinate different fields of specialization seamlessly.
One of our biggest challenges was working together efficiently, especially because each team member had different skills and schedules. A was better at Coding and electrical things. B was an expert in 3D modeling and was familiar with the 3D printing process. C was doing well with manufactured parts assembly and complete assembly of model. Each one had expertise in this because of our industrial experience. At first, this made it hard to stay on track, leading to delays and confusion. To fix this, we had a meeting to get organized. We discussed everyone's strengths and divided tasks so that each person focused on what they did best. We also scheduled Zoom meetings as well as physical meetings to track progress and keep each other updated. Regular check-ins helped us solve problems as they came up. This experience taught us that good teamwork needs clear communication and flexibility. When everyone knows what they were responsible for and understands each other's strengths and challenges, it's easier to avoid delays and keep things moving smoothly. This project showed us that adapting our plan and supporting each other helps us succeed as a team.

Describe a significant problem your team encountered and how you solved it.
In our problem we faced a problem with gear engagement. The gears, which are essential for transferring power, weren't always meshing smoothly. When gears don't engage correctly, it can cause jerky movements, excessive wear. To solve this, we examined the alignment and spacing of the gears closely. We found that slight misalignments were causing the teeth of the gears to grind against each other rather than fitting together smoothly. We redesigned the Gear with shaft multiple times and studied the Gear design parameters closely such as Module, Pressure Angle, no of teeth. And ran the simulation model of Gears in SolidWorks simulation to check the perfect gear engagement which helped us to resolve this problem. The other major problem we ran into was getting the conveyor to move fast in reverse direction. To solve this, we changed the code in Arduino IDE software multiple times and checked the system. We have also examined the circuit multiple times to resolve this problem. By tackling these two things-changing Arduino code and changing circuit multiple times-we made the conveyor more efficient, which was the goal of our project.
We had issues getting the motor to work at the beginning. We went through and checked our wiring, used multimeters to ensure continuity, and tested different components to see what the issues may be. Through our thorough checks, we were able to identify and solve problems.
A significant problem our team encountered was our gear hole being too high up on the body. Instead of reprinting another body, and wasting resources, we moved our stepper motor down and on to the screw-in backing. Another significant problem we encountered, as mentioned previously, was finding a time for everyone to work on the project due to our varying schedules. To solve this problem we discussed and divided the work so that not everyone would need to work on the project at the same time (ie. everyone was given a list of tasks and would work with those necessary and different times depending on those involved). This made it so everyone could contribute while still maintaining their own schedules.
A support pillar on the main case that was designed to hold the conveyor plate in place was very fragile and broke off during assembly of the conveyor system. It was realized that the structure would waste time and resources to reprint the same model, so the main case and conveyor plate were designed to just be mounted atop one another with screws to remove the issue of mounting a plate on a weak support structure.
A significant problem our team encountered was that none of us had any experience with coding or design for this project. To get started, we tried some random examples to see how things worked. By experimenting, we learned how to troubleshoot and slowly started understanding the basics. The biggest challenge was figuring out how to code and insert buttons into the project. We tackled this by breaking down the steps and looking up tutorials online for each part. This approach helped us learn as we went, and we eventually solved the issues with coding and button functions.
One of the major problems we faced was that the gears were not properly aligned, and this caused a lot of friction and hindered rotation. After several tries of redesigning the gear, we realized that the issue was not only with the design of the gear but also with the assembly process. To overcome this, we changed the gear tooth profile and also the size of the gear to ensure that they fit well. Also, there were problems with the frame's structural integrity when 3D printing it, as some of its parts would crumble. We were able to solve this by decreasing the frame size as our professor suggested, which made the structure more stable.

What value does your project provide, and to whom? Who are the potential users or beneficiaries of your project?
Our simple, small scale project demonstrates a simple yet effective means of material handling that would be available for use in factories and warehouses. Conveyor belts are extremely common and are used in every industry, so many businesses would use a conveyor belt and benefit from it.
In regards to real world applications, on a greater scale, this project could be used by those who need a simple conveyor system. However, since conveyors already exist that do what we were tasked with having our conveyor do, most of the value comes from the project itself rather than the final design and product. Our project provides us with knowledge about manufacturing, skills using soldering, 3D printing and coding, and skills as working as a team.

A target consumer was not directly addressed when working on this project. This project, however, could see use as a prototype design or segment of a much larger conveyor belt system in assembly lines or other mass production-based facilities. The imperfections and areas of improvement can be analyzed by other engineers to understand where common mistakes occur in design and learn for the future.
Our project provides value by offering a streamlined and efficient conveyor system that can be used to improve manufacturing processes. The primary beneficiaries are manufacturing companies looking to automate or optimize their production lines. By making the system more efficient, companies can reduce labor costs, minimize human error, and increase productivity. Potential users include: - Manufacturing Facilities: They can implement the system to transport goods smoothly along production lines. - Warehouses and Distribution Centers: These facilities could use the system to move products or packages efficiently. - Educational Institutions: Schools and universities with engineering programs could use the model as a teaching tool to help students learn about automated systems and manufacturing processes.
Our project offers valuable applications in the field of advanced manufacturing, particularly in material handling systems and automation. Here’s a breakdown of the potential value it provides and the primary beneficiaries: Material Handling in Manufacturing Industries: Our gear rotation prototype demonstrates a practical solution for controlling the movement and direction of components within automated material handling systems. With precise motor control and synchronized rotation, our design can aid in the seamless transfer, alignment, and organization of materials within conveyors, sorting lines, and assembly stations. Manufacturing industries focusing on automation, such as automotive, packaging, and electronics assembly lines, where controlled movement of materials is essential for efficiency and accuracy. Automation Systems: The project serves as a model for creating compact, precise gear-driven systems for automation. The integration of Arduino and motor controls allows the gear system to respond to user commands or sensors, making it ideal for applications that require automated actions, such as positioning, rotational adjustments, or repetitive movements in robotic arms. Industries utilizing robotic systems, logistics companies using automated storage and retrieval systems, and laboratories needing precise automation for equipment like mixers, sample handlers, or inspection tools.
The Conveyor System Modeling and Manufacturing project provides value by enhancing the design and efficiency of conveyor systems used in industries like manufacturing, logistics, and warehousing. By modeling the system, the project helps design and test conveyor solutions virtually before building them, saving time, reducing costs. By creating detailed models of conveyor systems, this project allows simulations that predict how the systems will perform in real-world conditions, helping to optimize the design before physical construction. The main beneficiaries of this project are companies and industries that rely on conveyor systems to move materials efficiently. This includes manufacturers, warehouse operators, and distribution centers.

What were the most significant lessons you learned from this project?
The most significant lessons learned from this project was overcoming obstacles. We were not able to get everything to work exactly as we wanted, so learning to keep trying until we got it right was a large part of the project. We had trouble with our wiring which made us believe our motor was not working. We had issues with using the Arduino Nano which made us believe we would have to use the Arduino Uno. From all of these, we found the biggest lesson was to persevere until we were happy with our end product.
Most significant lesson learned is to accurately measure everything beforehand to avoid reprinting. To give ourselves enough time to meet all the deadlines. To work as a strong team to effectively get everything completed.
The internet proved to be a vital resource in the conception and design process of the project. With the wide multitude of information available, it aided greatly in improving the programming and prototype of the conveyor belt and its separate parts. Collaboration within the group allowed us to use our distinct backgrounds to work together on the project.

The most significant lessons I learned from this project are: 1. Importance of Teamwork: Collaborating with my team taught me how valuable it is to listen to each other's ideas and work together, especially when facing challenges. 2. Problem-Solving Skills: We encountered issues with coding and design, and learning to troubleshoot by experimenting with different examples helped us build confidence in solving technical problems. 3. Using Resources Effectively: We learned to use available resources like YouTube tutorials, online examples, and our professor's guidance to bridge gaps in our knowledge. 4. Patience and Persistence: Building something new, especially with limited initial knowledge, required patience and a step-by-step approach, which taught me the value of perseverance. 5. Practical Application of Theory: Applying concepts from our coursework, like conveyor system modeling, showed me the connection between theoretical knowledge and real-world project
Time management is one big takeaway from this project. In the beginning when it was first assigned, work was achieved at a bit of a slower pace than desirable, but work was still being done. As things drew closer to the deadline, unexpected issues arose in the last phases of prototyping. If work had begun earlier, there would have been enough time to resolve said issues. Some 3D modeling and CAD software was not up to date as well, causing unnecessary workarounds that added further delay and pressure on the team. These situations highlighted the importance of effective communication and coordination between a project team. While there can be major improvements to the team's conveyor belt design that were not implemented due to time constraints, such setbacks provide important insight and experience that will enhance the performance of its individual team members in future projects
The most significant lessons we learned include: The importance of prototyping and iteration: Creating multiple versions and testing different designs is key to refining and improving the final product. The value of interdisciplinary collaboration: Combining knowledge from mechanical engineering, electronics, and programming allowed us to tackle a complex problem and find comprehensive solutions. Effective communication and task management are essential in a team project: Clear delegation and regular updates ensure that all parts of the project are aligned and function smoothly. Attention to detail matters: Small misalignments or errors in design can have a big impact on functionality, so precision and testing are crucial in advanced manufacturing projects.
We gained a stronger appreciation for project management. We also realized the importance of going through multiple design iterations. Initially, we thought creating a good design meant getting it right the first time, but we learned that improvement is a step-by-step process. Each redesign taught us how to balance performance. This approach helped us see how decisions in one area affect the whole system. Overall, this project taught us not just technical skills but also how to approach complex problems, collaborate effectively, and think critically about systems. These lessons will help us with future projects and in our career as a mechanical engineer.

Figure 4. The Student teams with their conveyer projects

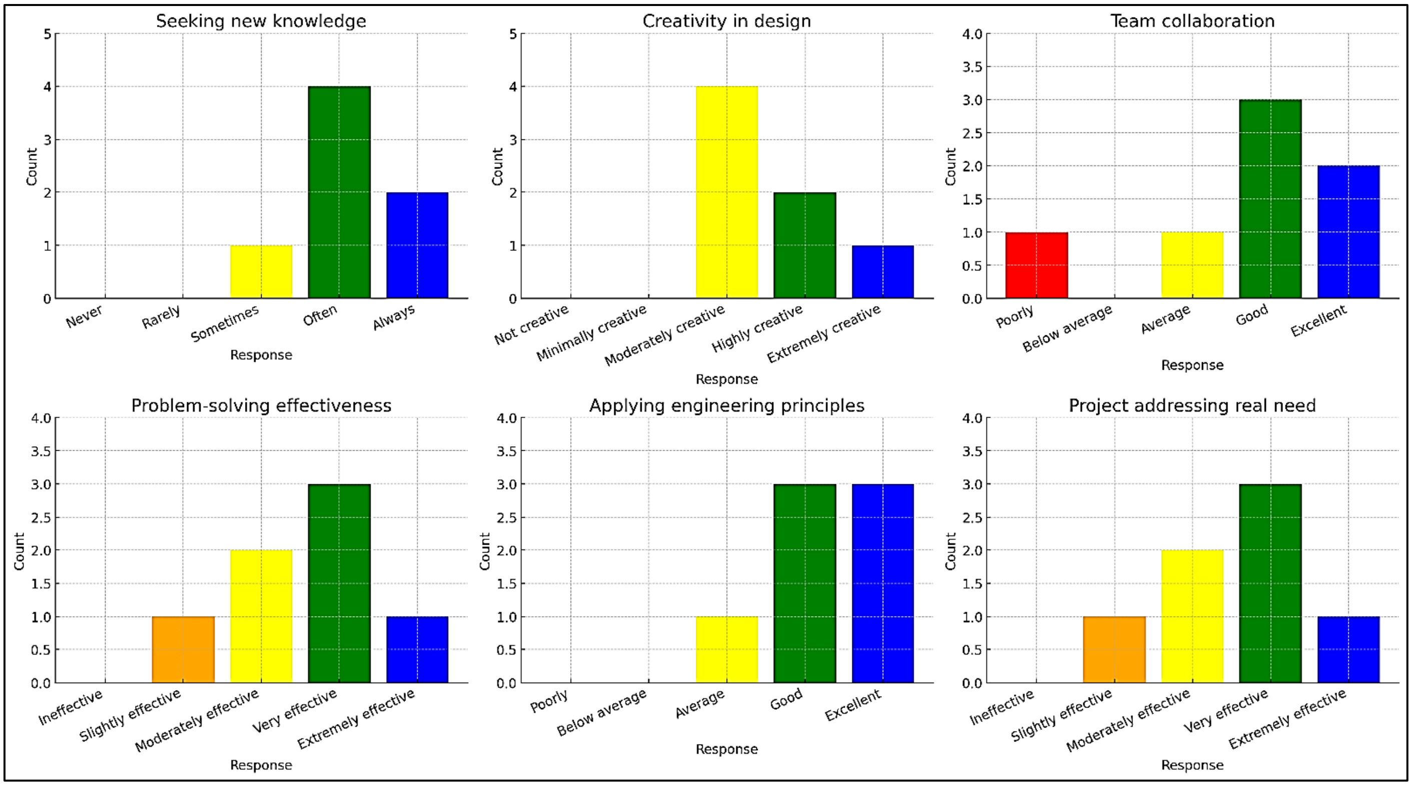

Figure 5. The histogram visualization of the Likert-scale based questions for the Conveyor Project.

Responses to the S-beam Project

How did curiosity about the subject help you in addressing project challenges?
Our curiosity about 3D printing led us to explore different ways to optimize the structure of the clip to minimize weight in interesting ways.
My curiosity mostly related to how I could improve the strength of the S-hook through the printing process. I was interested in seeing how I could change the infill and wall thickness to get a good strength to weight ratio. Other printing parameters such as mesh and the printer itself was interesting to me.
I was curious as to how we could geometrically optimize the hook to have the greatest ratio. This led me to researching topology optimization, where we ran simulations to cut sections of material from the hook, lowering the weight. I was also curious how the printing affected the ratio. By printing various samples and testing them, different layer alignments and infill settings and wall thickness settings resulted in very different results.
By applying knowledge from previous classes and combining it with the new material from this class, I felt prepared for this project. With additions research in areas that were needed for the optimized design, this project was both engaging and enjoyable.
I was unaware of how changes in geometry could affect tensile strength in a shape such as the S-hook that we are designing for the project.

Provide an example of a creative idea or solution you used in your project.
Rather than printing the hooks with different infill patterns using software, we just printed them in different orientations relative to a parallel axis to simulate different patterns/angles of feed direction.

A creative idea we used was different infills at different places in the design based on projected stress of the hook upon testing.
Our group ended up favoring wall thickness over infill density. We found that thicker walls with barely any infill performed better than thinner walls with more infill.
Compared to annealing my S-hooks, I would say varying the infill of my part was moderately creative. I think having to print parts prior to the testing, maybe toward the middle of the semester, would have helped me understand the drawbacks of my design and what I could do better by seeing others. Two tensile tests would have been nice.

Describe a challenge your team faced during collaboration and how you overcame it. What did you learn about teamwork in this project?
I believe the difference in skillset made distribution of the project a bit difficult. Due to my teammates being ECE majors, all of the 3-D printing related work was dealt to me. Simulation, design, prior testing, and printing was dealt to me and I overcame this mostly due to me having a printer at home. One thing I learned about teamwork is that the one with the most knowledge on the topic should take lead.
It was difficult to find time to test on the machine so we tested the hooks by hanging it on a bar and hanging weights from it. This is fine for finding the maximum weight it can withstand, but gives less insight into the actual curve and how it is straining with more weight. Having assigned tasks and deadlines with each role would have been helpful in making sure everything was done in a timely manner.
There were initial challenges with testing the design and running stress/strain simulations, but the team kept altering the design till we found something suitable.
We did not spend much time deliberating tasks outside of the classroom, so this led to not much being done during free time. I learned that communication is very important when working on semester long projects.

Describe a significant problem your team encountered and how you solved it.
Finding the time to print parts outside of class time on campus. This was solved through one of our team members printing the parts using their personal printer at home.
We solved the problem tasked in the project by performing stress simulations in Solidworks, and doing research on 3D printing with different infills.
We faced issues with the performance of certain prototypes, but through redesigns and re-testing, we found a good solution.
I think the biggest problem for my group was figuring out what worked and what weight sacrifices would benefit our weight to strength ratio. I used Solidworks simulation to figure out where high stress areas were and choose to use a higher infill at said areas. However, I should've used a bit more given our results.

What value does your project provide, and to whom? Who are the potential users or beneficiaries of your project?
I believe the intention of reducing the amount of material needed to create the parts would benefit consumers of our product. Lower the cost would also benefit our end due to less material.
Understanding the process of iterative design is a critical need in engineering. In this project, the changes in each iteration included different geometries and different orientations on the printer.
Anyone who is in need of a strong and durable s hook.
The project provided the value of insight and experience to myself and my other team members in that I have further learned the processes of innovative design and manufacturing. I have also gained experience in problem modeling/simulation software.

What were the most significant lessons you learned from this project?
The most significant lesson learned is to begin working on semester projects early rather than later to reduce workload at the end of the semester.
The most important lesson was the importance of communication within a team project setting, as it can make or break the execution of a project.
I learned how important iterative design and testing/analysis can be for such a simple design. Additionally, the tradeoff between strength and weight is such an important topic in engineering, and this project highlights that.
Time-management was a big one, especially with regards to print times. I also found the collaboration between groups was very beneficial to get ideas of how we could enhance our design.

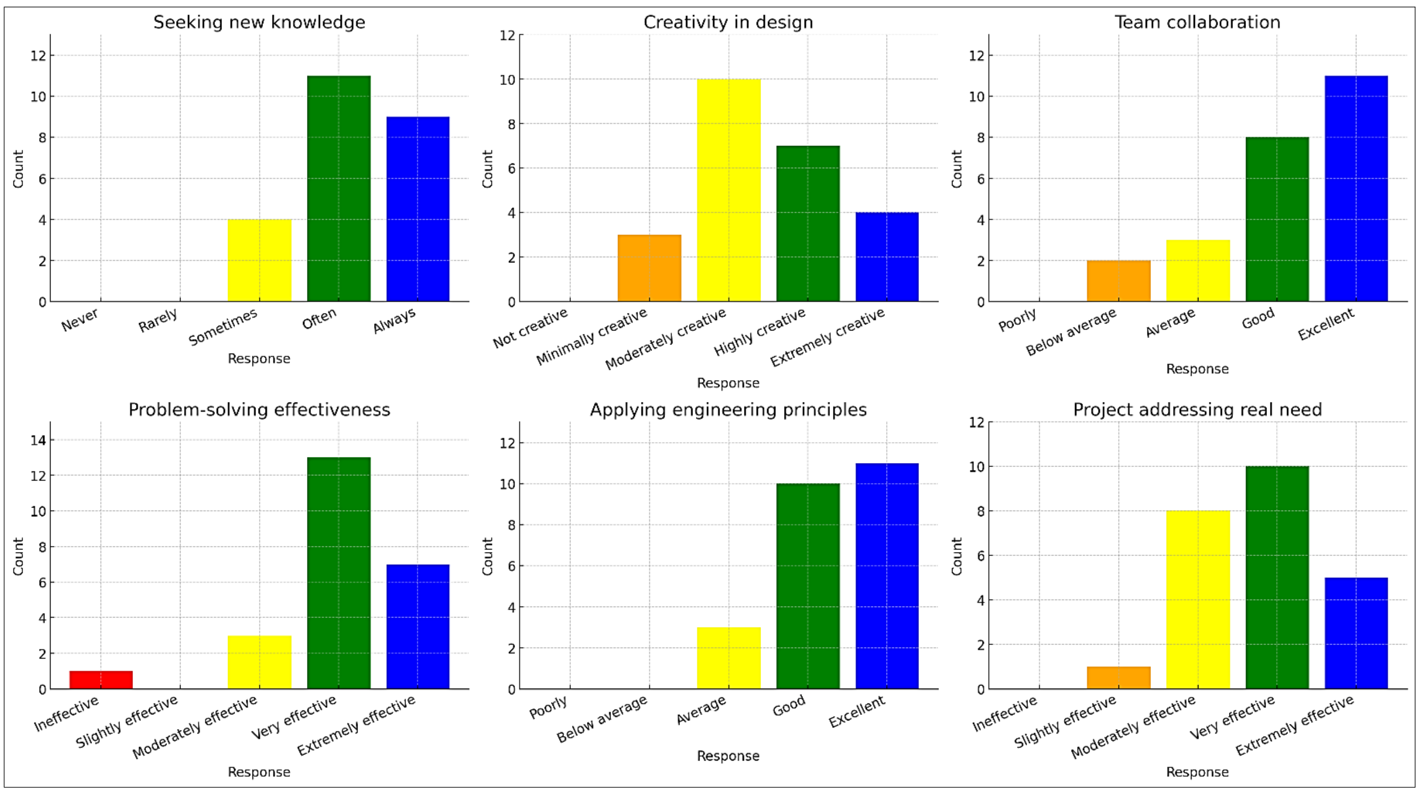

Figure 6. The histogram visualization of the Likert-scale based questions for the S-Binder Project.

5. Conclusions

From the student responses, several key conclusions can be drawn. Regarding the role of **curiosity** in addressing conveyor project challenges, many students were working with unfamiliar technologies such as stepper motors, gears, and 3D printing. Their curiosity led them to actively seek out new knowledge, whether through online resources, tutorials, or hands-on experimentation. This eagerness to learn helped them bridge gaps in their understanding and improve their technical skills. They experimented with different gear configurations, optimized motor control, and sought ways to enhance code quality. This iterative approach led to improved system performance and more refined solutions. They learned to use tools like SolidWorks and Cura for design and manufacturing, refining their skills through trial and error. For the S-beam project their interest in improving weight efficiency and strength led them to investigate factors such as infill density, wall thickness, and layer alignment, allowing them to optimize the S-hook's strength-to-weight ratio. Curiosity also prompted research into advanced techniques like topology optimization, where simulations helped refine the geometry by reducing unnecessary material.

When asked to provide an example of a **creative idea** or solution they used in their project, their responses largely indicated that they demonstrated creativity by developing innovative solutions to design, assembly, and functionality challenges. For example to optimize space and make the conveyor system more compact, they used detachable pegs to simplify gear assembly, redesigned rollers as separate parts, used customized button layouts for better user experience and an intuitive interface, using idler gears to correct rotation misalignment, and improved circuit stability by switching from jumper wires to 22AWG wires. For the s-beam project the student responses indicate that instead of relying solely on software-generated infill patterns, they experimented with printing orientations to simulate different stress distributions. Some groups strategically varied infill density based on projected stress areas, while others prioritized wall thickness over infill density, discovering that thicker walls with minimal infill provided superior strength. Additionally, one student compared the effectiveness of varying infill with annealing, recognizing the value of iterative testing in improving design.

The **challenges** faced by the team revolved around coordinating schedules, managing different skill sets, and maintaining effective communication. To overcome these hurdles, the teams adapted by dividing tasks according to individual strengths, utilizing flexible meeting arrangements, and prioritizing constant communication. This approach helped resolve scheduling conflicts helping the team learn that successful collaboration requires flexibility, clear communication, and a willingness to adapt to unforeseen challenges. In case of the s-beam project too similar challenges stemmed from skillset differences, time constraints, and inadequate communication outside of scheduled meetings. Finding time to test the machine proved difficult, and testing methods were not as comprehensive as needed. Through these challenges, the team learned the importance of clear task delegation, setting deadlines, and maintaining consistent communication to ensure timely completion of all aspects of the project.

When asked regarding the **value created** or contributed by their projects the conveyor project responses indicate that students realized the project provides significant value across a range of industries, particularly in manufacturing, logistics, and education. While the conveyor system itself is not groundbreaking due to the existence of similar solutions, the project offered valuable hands-on experience for the team, enhancing skills in manufacturing, soldering, 3D printing, and coding. The students mentioned that such a project could serve as a teaching tool allowing engineers to analyze similar designs for future improvements in industrial systems. For the s-beam project the responses highlighted the benefits of iterative design, cost reduction through material efficiency, and gaining practical experience in areas like manufacturing, simulation software, and problem modeling.

In all of this the students learned several **key lessons** from their project, including perseverance, teamwork, problem-solving, and time management. Many faced technical challenges, such as wiring issues and outdated software, but they learned to troubleshoot problems and persist until they achieved a working solution. The importance of careful planning, accurate measurements, and early preparation was also highlighted, as last-minute issues added pressure to their timeline. They recognized the value of prototyping and iterative design, testing, and the engineering tradeoff between strength and weight and that refining a project through multiple versions leads to a better final product. Additionally, students gained an appreciation for using external resources like online tutorials and professor guidance to enhance their knowledge. Lastly, collaboration between groups proved beneficial for generating new ideas and improving designs.

Following an analysis of **Entrepreneurial Mindset & Business Model Canvas** in student responses; many students emphasized how curiosity helped them address project challenges, particularly when working with new technologies. Their eagerness to explore advanced manufacturing techniques, and improve their designs demonstrates a problem-solving mindset—a key entrepreneurial trait. Instead of just completing the project as assigned, they actively sought new knowledge, experimented with different methods, and refined their solutions iteratively. This reflects an innovation-driven approach similar to how entrepreneurs identify and refine market solutions. The students also understood the broader applications of their project beyond just an academic exercise. Some teams highlighted how their project could benefit industries such as manufacturing, logistics, and warehousing. Others acknowledged that while their prototype was not revolutionary, the learning process itself provided value through the development of skills. This mirrors the business model concept of value proposition - understanding the needs of end users and refining products to better serve them. Many students displayed an entrepreneurial ability to maximize resources and minimize waste, whether by refining designs to avoid unnecessary reprinting, reusing materials efficiently, or troubleshooting problems systematically. The idea of iterating rather than discarding and starting over aligns with lean startup principles, where minimizing waste and continuous improvement are key. A significant challenge students faced was coordinating efforts among team members with different schedules and skill sets. Their solutions—dividing tasks strategically, leveraging each member's strengths, and maintaining regular communication—mirror how entrepreneurial teams operate in fast-paced environments. The ability to adapt, delegate, and leverage diverse expertise is crucial in startups and business model development.

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