Experiential Learning in Manufacturing Process Development through an Assembly Workcell

Mx. Gracie Elizabeth Brownlow, Michigan Technological University

Gracie Brownlow earned their Bachelor's degree in Mechanical Engineering from Michigan Technological University in Spring of 2025 before continuing their education with a Master's in Mechanical Engineering. Under the direction of Dr. Vinh Nguyen, the focus of their graduate studies is on how experiential learning experiences can be used to improve the outcomes for students studying in the introductory manufacturing courses. The current project described in the paper focuses on the work that will be implemented into the next school year for students to develop themselves as manufacturing engineers before entering the workforce.

Vinh Nguyen, Michigan Technological University

Dr. Nguyen started his appointment as an Assistant Professor at Michigan Technological University in 2022, where his research focuses on advanced manufacturing through Industry 4.0, human-robot-machine interaction, and physics-based/data-driven modeling. Dr. Nguyen has developed solutions for a variety of production processes including machining, additive manufacturing, metal forming, and robotic assembly to promote smart and sustainable manufacturing. Dr. Nguyen also conducts research in general industrial automation including autonomous vehicles and industrial robotics.

Prior to his appointment at Michigan Technological University, Vinh was a National Research Council Postdoctoral Fellow at the National Institute of Standards and Technology from 2020 to 2022. He received his PhD in Mechanical Engineering and his MS in Mechanical Engineering and Electrical & Computer Engineering at the Georgia Institute of Technology in addition to receiving his BS in Mechanical Engineering and Electrical Engineering from Rensselaer Polytechnic Institute.

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Abstract

Direct experiential learning experiences allow students to obtain critical thinking skills and experience without undergoing internships or co-ops. This paper presents the design and development of an experiential experience lab course that focuses on manufacturing process development for the assembly process. The lab course was developed to supply students with focused, learning-based assembly goals over the course of a semester. The students are expected to exhibit their learning through team-based reports that provide a theoretical company with the organization, plant layout, and duties of each workstation within the workcell. This cohort-driven approach will provide a focus for students to make decisions that will be the best outcome for the exemplary company. With these goals, students will then use the workcell to practice process design methods in the assembly of a racing drone. Manufacturing concepts including Quality Control, Reverse Engineering, Lean Manufacturing, and Six Sigma are practiced through this workcell and retention for these concepts are promoted through the addition of empathizing with real-world problems and operators. This workcell's design aims to yield an experiential experience for students in process development of manufacturing in the advancement of manufacturing knowledge and skills to prepare students for the production workforce.

Introduction

Employment in manufacturing is in high demand, and mechanical engineers make up 46.9% of the population of engineers in the manufacturing sector [1]. Experiential manufacturing education provides a contribution to students' confidence and abilities in the manufacturing field through the lecturing and practice of manufacturing concepts. Supporting students to practice these concepts outside of the lecture through meaningful activities builds and solidifies the knowledge that students obtain in addition to building confidence for students to apply the concepts in real-world applications [2]. To provide more methods of solidifying understanding in an introduction to manufacturing lecture, this work aims to implement a new lab course to coincide with the currently taught manufacturing lecture to apply hand-on learning and critical thinking for solidifying understanding of material to be applied in students’ future careers.

Surveys have found that students find multiple aspects of a career in manufacturing attractive, including, design, processes, hands-on work, and the tangible outcomes [3]. This information reveals the specific aspects of manufacturing that attract students into the field and guides the lab activities that result in the best outcome of student engagement, as studies have found that working with people's curiosity helps in creating motivation to ultimately facilitate better retention of knowledge [4]. These studies are the foundation for a lab course that builds on students' desire for hands-on, creative learning of the different processes and aspects of manufacturing with an ultimate goal for students to participate in course activities.

The development of the activities also must go beyond only solidifying theoretical concepts, but also building practical soft skills for students to use in their careers. The manufacturing industry is looking to hire high-quality graduates that will deliver more than solving problems, but also be able to do problem solving [5]. Through simulated work in a workcell with instructions, students will be able to work through the provided goals and develop their own conclusions based on the information and data collected. The instructions and deliverables provided for each activity encourages students to explore further into new advancements or other methods of engaging a problem. This will promote students' critical and creative thinking skills towards their future careers and generate a positive impact for the industry.

The accompaniment of lab activities alongside a lecture provides an opportunity for students to strengthen their understanding of the industry of manufacturing, as well as exploring their interests. By developing an assembly workcell with guided instructions that allow for students to plan and execute the necessary steps to produce a racing drone, the manufacturing course is promoting growth in skills, such as teamwork, efficiency, and problem-solving, for students to utilize in industry. The remainder of this paper is outlined as follows. First, the assembly workcell and product of interest are described. Then the instructional materials associated with the workcell are presented and followed by discussion of the theoretical foundations behind the design of the instructional materials. This paper then ends with concluding remarks followed by discussion of future work.

Workcell Description

The physical workcell is designed with the consideration of limited space with maximized enjoyment and experience for students. With that, each workcell station consists of a table, a double-sided pegboard, a timer, tools, and assembly parts. This baseline workcell includes many of the aspects that are utilized in a manufacturing line to create a familiarity between a manufacturing environment and the classroom setting. Figure 1 shows the layouts of an individual workcell.

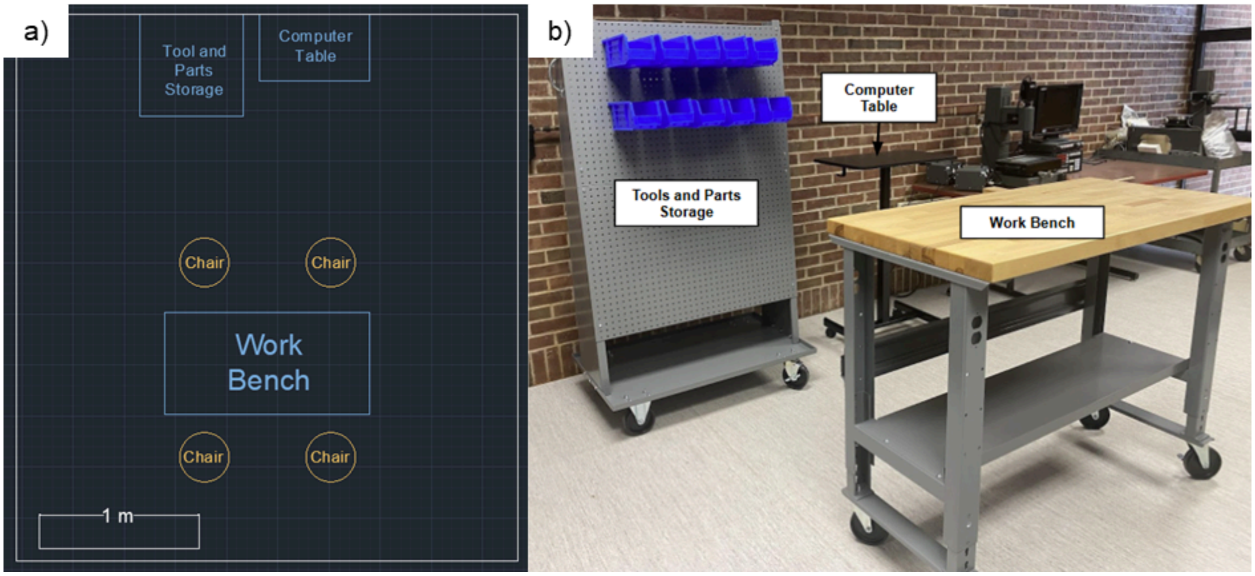

Figure 1: Workcell (a) AutoCAD 2D drawing and (b) physical setup.

In this work, a double sided pegboard is utilized as a method of adjustable storage. Allowing for parts and tools to be easily moved allows for students to explore ergonomics. As the space will be shared amongst many students, the layout must allow students to maneuver tools to improve efficiency in their work as well as minimize injury from the repetitive motion of assembly. For example, one student can rapidly organize tools to fit their working style, but the student afterward can adjust the layout to better fit their method of assembly without spending the lab's time. Also, a student who is working may notice that reaching for the parts when they are high up is an ergonomic risk and swiftly adjust it before continuing the exercise.

A timer is essential for understanding cycles and takt time. The workcell includes one that is easily viewable and has the ability to quickly stop and start to promote the collection of accurate data that can then determine errors in their cycles. The selection of one with a button to control the timer was to simulate large product assembly lines with automated motion, where a button is commonly the signal to advance the product to the next station and records the time of the cycle at each station. This makes a clear signal to not only the students themselves but also the others in the class, indirectly promoting a sense of competition to generate the best cycle time [6].

The final component of the workcell is the product. Having an ultimate goal and a familiar product allows for students to grow in confidence as they work. For the available space and time, it was determined that a Mark4 5-Inch First Person View racing drone shown in Figure 2 would be an adequate product. The drone allows students to visualize an entire process in a short period of time, including the understanding of subassemblies, strict process, and quality control. The drone is able to meet these different aspects because of its mix of mechanical and electrical components. The electronic speed controller (ESC) and motors are soldered together outside of the lab, but students are expected to incorporate the subassembly time in the takt time. The process of the assembly also must be completed in a particular order to ensure no damage to the ESC and to layer the parts on top of each other for a working drone. The drone is able to provide students with practicing different methods of quality checks such as a flight test at the end of the build or tightness of the screws. Beyond the experience from the drone, the device is also practical through including all of the important manufacturing concepts while being straightforward enough to integrate into a two hour lab period. For these reasons, the drone provided the best opportunity for students to strengthen their understanding of manufacturing processes.

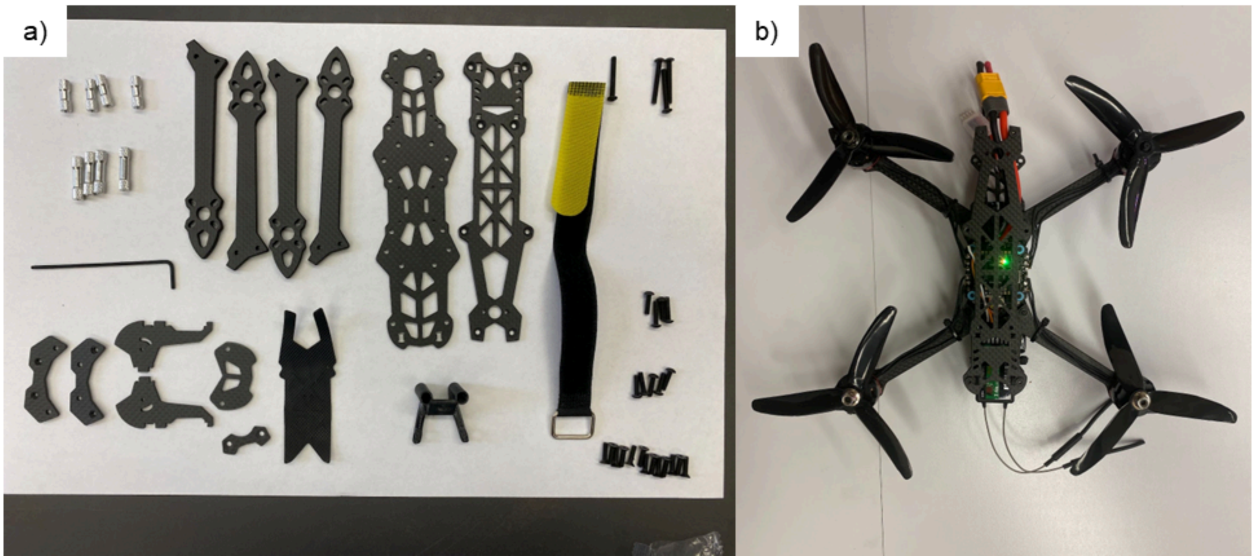

Figure 2: Drone assembly in (a) disassembled form and (b) physically assembled.

Instructional Materials

The materials that were written for the course are built for a cohort of 3 to 4 students per work cell. The students are expected to work in cohorts of their peers to develop their abilities to work in teams as well as have other members to compare their work with. As seen in the manufacturing industry, the presence of other people improves work ethic and quality of product. The lab activities holistically are designed to provide the students a working goal to improve course content retention [2]. The goal that students have been provided is that, while working through the lab activities, they will be developing a manufacturing plant for an up-and-coming drone manufacturing business. Students must provide for each work station, the tasks of each person, the layout, the materials, and the cost analysis of the project at the end of the course. By having students work through a goal established as if they are hired engineers allows students to not only solidify their manufacturing concepts, but practice professional communication, applying problem-solving skills to what may be similar to future careers, and analytical thinking with a clear goal.

Each semester of the lab consists of six lab activities over the course of the semester. Each lab builds upon one another to build towards the final product that is due to an exemplary company, as well as develop writing skills, communication, teamwork, critical thinking, and creativity in an interactive procedure.

The labs are described as follows:

1. Quality and Reverse Engineering Lab: Introduction to the drone assembly and necessary parts of the build

2. Assembly Lab: First full drone assembly without instructions or manufacturing concepts

3. Cycle and Takt Time Lab: Breakdown of tasks for each work station to develop product assembly

4. Layout Lab: Apply the cycle times and tasks of each workstation to find the best assembly line layout

5. Tools and Material Handling Lab: Develop the set up of each workstation on assembly line

6. Final Product Lab: Test and finalize the manufacturing plant using previous work

Quality and Reverse Engineering Lab

The beginning of the lab section will be building familiarity with the product and the students with the Quality and Reverse Engineering Lab. This lab has students work with a fully assembled drone and deconstructing it. Through the deconstruction, students will record a worksheet with measurements of the parts and take inventory of every part that is used to have a complete product. For example, Figure 3 shows using calipers to note the thickness of the frame at one point to compare to the other parts. This allows for students to have an introduction into the manufacturing process and begin comprehending the necessary tolerances and quality checks of parts to have the best product possible.

Figure 3: Example of measurement using calipers.

Students will also learn how to use a Coordinate Measuring Machine (CMM) to develop their machinery skills and learn the benefits and disadvantages of measuring with a CMM and by hand. The deliverables for this activity are for students to describe the disassembly process of the drone, which is important for the next lab activity. The Quality and Reverse Engineering Lab provides an overall introduction to the drone, which then will be tested in the Assembly Lab where students must rebuild the drone with minimal instructions. The importance of having the Quality and Reverse Engineering Lab before the Assembly Lab is to ensure students are not left with no direction or understanding for the Assembly Lab, but still encourages exploration and the initial development of empathy to provide a more impactful learning experience [7].

Assembly Lab

The second lab within the lab section is the Assembly Lab. This lab aims to provide students with the parts and tools for the drone that the Quality and Reverse Engineering Lab had given them an introduction to. However, the provided materials for assembly are not organized. The team of students must work together to complete the drone as accurately and quickly as possible while recording their time. With the quickest cohort to have the build checked by the Teaching Assistant (TA) and it being correct will receive bonus points as an incentive to do a satisfactory assembly in the shortest amount of time. If students have the drone checked by the TA with defects, they must add 2.5 minutes for each incomplete process to their final time for repairs. This lab also includes minimal instructions for students because this lab is meant to be a lab that generates empathy in students working in manufacturing. Human interaction is an important part in being able to be an adequate manufacturing engineer, communicating with operators on an assembly line opens the door to new perspectives and knowledge from the individuals who build these products and have learned their job on a deeply intimate level [7]. This lab is created as an illuminating experience for students, some who may have no experience working on an assembly line, to build the connection between the quality a manufacturing engineer puts into their work and the outcome for the people who are working with the product. The Assembly Lab shows students how poor quality in writing instructions, organization, and support causes a negative impact not only on the product, but also the relationship between the engineers and the operators. The deliverables on this lab asks students to place themselves as doing this job in a poor quality environment for the same amount of time as the average assembly operator and to describe what they would change about the station they worked at to improve the experience for anyone who works in an equivalent environment.

Cycle and Takt Time Lab

The Assembly Lab showed the worst case scenario and the impacts on not only production but human interaction. The Takt and Cycle Time Lab work to begin reorganizing and addressing some of the complications that were found in the Assembly Lab, specifically the lack of instructions and breakdown of work for each person. To begin, this lab has each student in the cohort do a time breakdown of one of the videos of a professional assembling the drone. Each cohort member will have a different video to analyze to practice writing out concise and accurate instructions, which will be important later in this lab activity. Figure 4 shows the main objectives of the three videos that students will analyze.

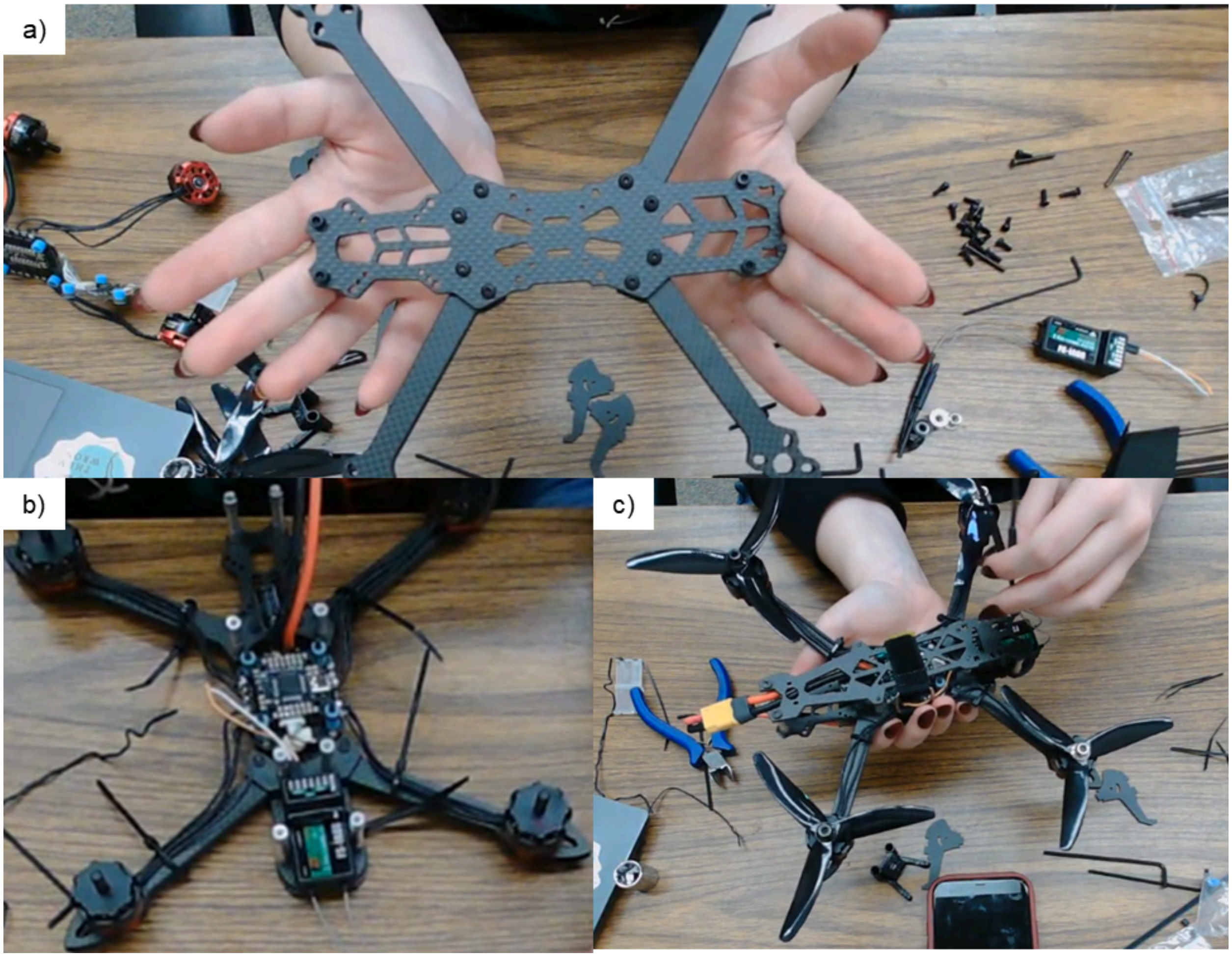

Figure 4: Assembly videos for (a) assembling base frame, (b) fastening electrical components, and (c) final assembly.

The ability to write out work instructions in a manufacturing environment allows for easier training that also highlights important steps in production to ensure the best safety and quality for operator and product. After the analysis of time and steps, the team will work together to balance out the steps, placing them in order and adding prep work that can be done to prepare for the next drone on the assembly line. The goal is for the team to have every work set be approximately the same amount of time to minimize downtime for an operator. After that is completed, each member of the team will receive instructions that were written by another team member. They must build the section of the drone that the instructions they received describe using only those instructions and the students must record the time the student took to do each part of the process. The team will then compare the expected time that was selected for that part and adjust the work instructions as necessary to meet the cycle time. This serves the purpose of students writing instructions not for themselves, who watched the videos, but instead someone who has not seen their training. The objective of this is to not only for students to adapt writing skills that explain instructions in a manner to someone who has not been on the assembly line, but also for peers to be able to give and receive feedback on their writing and as a team recognize where steps of assembly may need to be adjusted to meet the cycle and takt times. This lab promotes writing skills, communication, constructive criticism, being able to interpret instructions, understanding and developing takt and cycle times which are all key in manufacturing engineering.

Layout Lab

At the end of the Cycle and Takt Times Lab, students have now developed their workstation tasks for assembly and with that they must find the best way to organize their assembly line. Although it is typical for a straight line assembly, the Layout Lab looks at students to explore different types of assembly lines, from the shape to the mode of transportation between each station. Students will have the opportunity to follow new instructions to assemble Legos shown in Figure 5 to reduce the fatigue of working with the drone. They must assemble the part and use the conveyor to move the part to the next assembly station. Students will be given time to work on a roller conveyor, a belt conveyor, a table that students will push the part to the next cohort, and a rolling cart that will be used to transport. They must also set up each station with different configurations, such as I-Line, U-Line, L-lines, and a shape of their choice. Students will then have to record the cycle times as well as compare the convenience of each method and the overall cost of using the different types of transportation methods and configurations. Students working in this lab learn the different opportunities that come with line set up and begin comparing the cost impact of each method and the possible waste that comes with the different methods. This lab is the first step to the final module where students will be designing a plant layout to give to the company that students were theoretically hired to build a new manufacturing plant for.

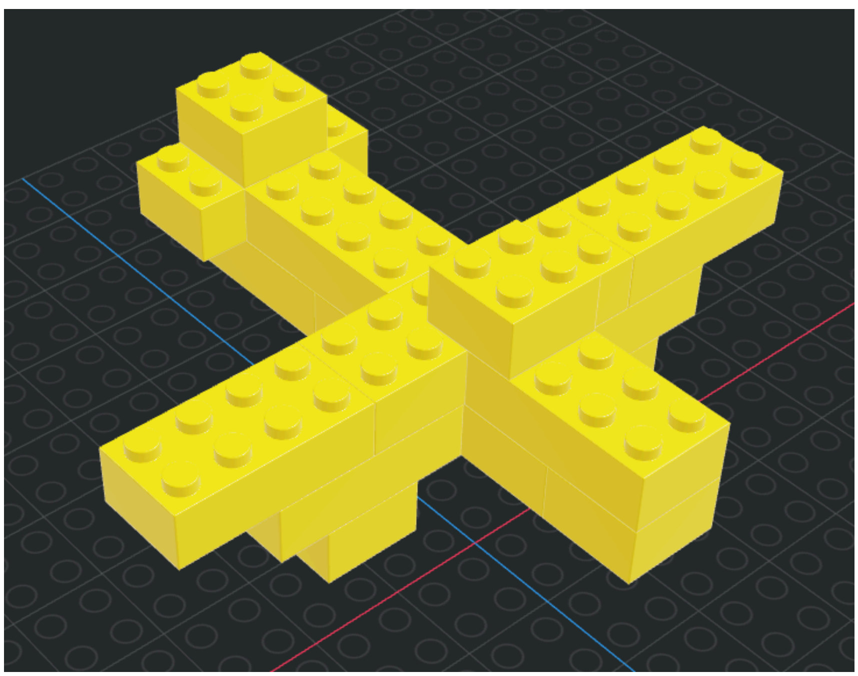

Figure 5: 3D model of the Lego build.

Tooling and Material Handling Lab

At this stage, students now have to construct their assembly line configuration, type of transportation, and also the tasks of each workstation for assembly of the drone. To complete the workstation layouts, students will design and set up the parts and tools of each station to fit into the configuration in the Tooling and Material Handling Lab. Each workstation will use the tooling and parts storage to hang bins and tools that are necessary for completing the tasks determined in the Cycle and Takt Time Lab. They will work through the assembly at each station, testing different configurations to determine which has the best time and best ergonomics for the operator. Figure 6(a) shows an example of an optimal layout, where the operator would have easy access to tools and parts, and Figure 6(b) shows an example of a not optimal layout, where the operator would have to turn around and step to access tools and would have to reach higher to collect parts. To achieve the best outcome, each teammate will go through the assembly with the configuration that was previously selected by the students in the Layout Lab and record what steps slowed their process or would cause fatigue. Having each member of the team conduct this operation ensures people of different skills and physical attributes are able to work with this station setup, which is a reality when working in a manufacturing environment. For the deliverables, students will also discuss how they will be refilling parts on the line and the method of storage. By having students conduct this exercise, they will be able to understand ergonomics, material handling, and the importance of thinking beyond just the direct production line.

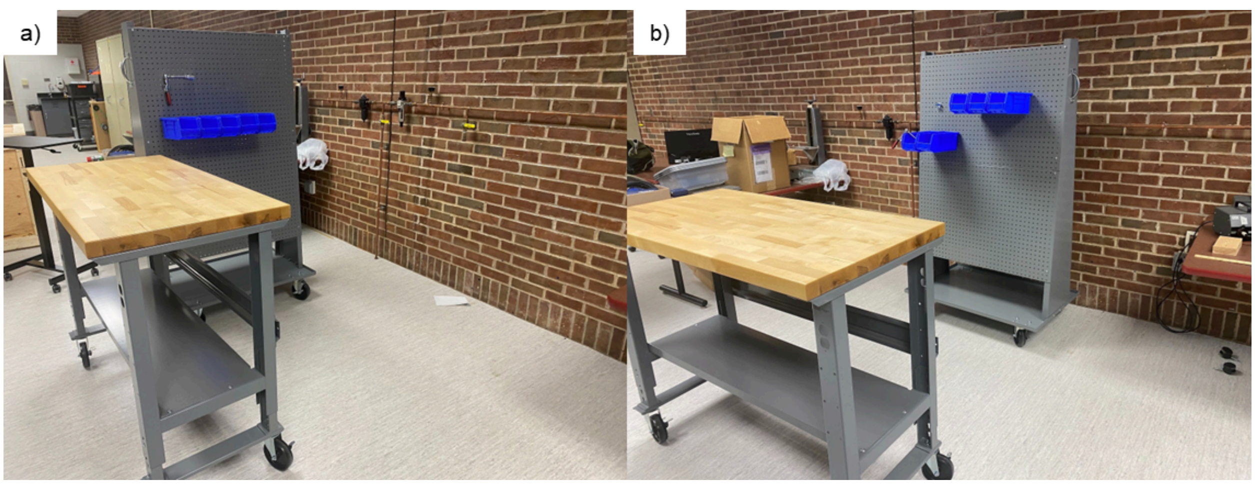

Figure 6: Layout examples for (a) optimal and (b) suboptimal cases.

Final Product Lab

The final section of this lab is to be able to take all the information compounded over the semester and apply it to complete a simple manufacturing layout, economic estimate, and a final report to the company. Students will be given an economic analysis spreadsheet which includes many of the costs of parts, storage, and personnel in order to minimize the cost but meet the necessary requirements for the company. There is also a 2D AutoCAD outline of a building which students will draw their storage, line configuration, on line storage, and the room for each personnel from an above perspective. This is to have students understand space and make the best use of a given area to meet the requirements of the project. The report will explain the choices the students made and their reasoning to show the overview of concepts that they have solidified from the combination of the lecture and lab. Finally, students will have a presentation to pitch their design of the building, economic estimate, and the plan for each work station. They will be presenting to not only the instructor, but also their peers, as the team with the best report will be given extra credit points for showing the best understanding of the materials and goals of the lab activities. The Final Product Lab has students practice their writing, presentation, and analysis skills to end the lab with the chance to show what students have learned and gained from the course as well as compete with other students for peer learning.

Discussion

The establishment of these labs in the manufacturing course builds students' understanding of the concepts taught during lecture and improves on skills in writing, communication, constructive criticism, and teamwork. Retention of material is proven to be better with the inclusion of hands-on learning, the use of emotions to develop a deeper understanding, and an overall project builds students to be more prepared for future careers. The focus on a drone is similar to that of a factory, where they develop one product and work to develop the product and the process to be as efficient as possible. By implementing a lab that will be similar to real-world manufacturing environments, it creates necessary connections for students to move into the workforce with confidence and experience. The Quality and Reverse Engineering Lab and the Cycle and Takt Time Lab provide students with the required aspects of designing a production line and help students in practicing these skills to meet the requirements necessary for completing the tasks. In conjunction with those, the Assembly Lab, Layout Lab, Tooling and Material Handling Lab, and the Final Product Lab, students are expected to use the knowledge and skills that students' have developed thus far to think independently and creatively to achieve the objectives. With each lab, students practice concepts on manufacturing that are meant to be applied and understood beyond traditional lecture environments, but also seeing the humane parts and the opportunities that people provide.

Conclusion

The introduction of a hands-on lab in addition to a lecture for an introduction to manufacturing course provides students with an opportunity to solidify their concepts from lecture, develop skills in professional writing and proactive problem solving, and progress their teamwork skills and communication. Through a semester with the six labs described in this paper, students are able to advance the skills described to carry into future careers. The use of a drone in the lab setting allows students to learn about manufacturing processes similar to a traditional manufacturing environment. Students will be able to familiarize themselves, develop ideas, and test the drones to satisfy a demand for hands-on experience and develop critical thinking and problem solving skills. Students will also be able to adapt the final product to meet the requirements set and provide an overall solution to the project. From the lab courses, students will be better understanding of the material covered in the introduction manufacturing course and better equipped for careers after graduation. Future work will involve collecting student feedback in a condensed study that will occur over the span of a few hours rather than an entire semester. Hence, the instructional materials will be redesigned for accelerated learning while maintaining the core essence of the semesterly content.

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