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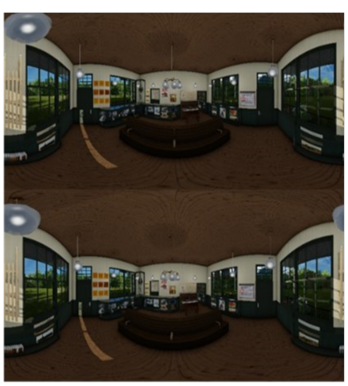
In This Issue (p.5)
AI, NLP, and Simulation Software in Education

Philip Weinsier, TIIJ Editor-in-Chief

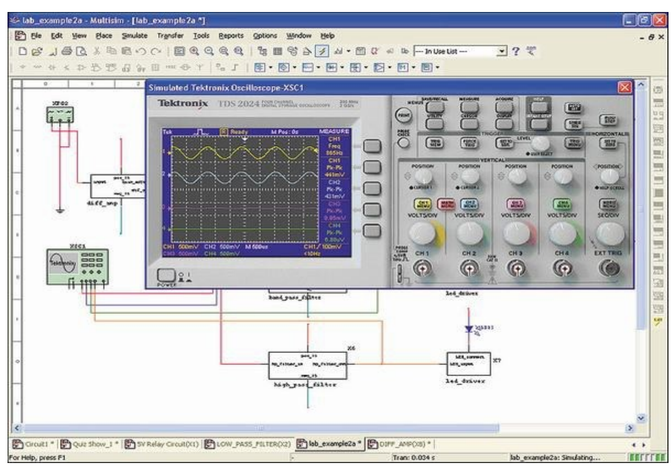
More than likely, you are already utilizing some kind of simulation/animation activities in your classes; I certainly am, and have been adding new activities and different kinds of software packages over the years to enhance student learning. If you are not currently offering such activities, perhaps this would be a good time to consider whether they might be right for you. Simulations are computational learning tools that let students apply their theoretical knowledge to real-world issues or learning settings, while observing the results without suffering any actual loss. In my electronics labs, it can be expensive and dangerous, when students (or I) blow up their circuits. Using software simulations, however, all we risk is the loss of a few Coulombs' worth of electrons!

On the whole, education is becoming more engaging, practical, and immersive, due to technology, particularly natural language processing (NLP). NLP is an umbrella term used to describe technologies such as artificial intelligence (AI), machine learning (ML), and machine perception (MP), among others. NLP allows us to perform tasks by mimicking human intelligence and simulating real-world situations, which allows us to help our students grasp concepts better, remember them longer, and show more interest.



Almost daily, news reports would have us believe that AI is bad and that we need to stop it (we can't) or regulate it (more likely); or it's going to change the world for the better (certainly, if we survive) and that it's dangerous (in the wrong hands, most things are). But, in fact, new ways of using AI in education are constantly emerging, the goal of which is to enhance the learning experience, improve the effectiveness of instruction, and provide learners with more personalized and efficient education.

AI can analyze students' strengths and weaknesses, identify areas where they need improvement, and tailor learning materials to suit their individual needs. This personalized approach ensures that students get the right level of challenge and support, making learning more effective and engaging. Examples could include intelligent tutoring systems, learner support chat bots, automated grading tools, content recommendation systems, and data analytics for optimization. But wherever you come down on how the world is going to change tomorrow, take a look today at our featured article (p.5) on how these authors are using simulation and animation software in their classes.



Editorial Review Board Members

Utilizing Simulation and Animation Software in Design Projects of Multi-Semester Courses

Negar Heidari Matin, University of Oklahoma; Ali Eydgahi, Eastern Michigan University

Abstract

Cumulative learning is the cognitive process by which students can accumulate knowledge and abilities that serve as building blocks for their subsequent cognitive development. The training of students as innovative thinkers in dealing with today's complexity of global challenges requires an integrated approach to educating students that integrates information, data, techniques, tools, perspectives, concepts, and theories from two or more courses and answers questions beyond the scope of single-course learning. In this paper, the authors propose activities that can be used by both undergraduate and graduate students in architecture and interior design programs in multi-semester continuous courses. The proposed hands-on activities utilize a variety of software packages for 2D-CAD drafting, 3D-CAD modeling, building information modeling, rendering and representation, building performance evaluation, and visualization. Through these hands-on activities, students learn how to use AutoCAD, Adobe Photoshop, SketchUp, Revit, Lumion, and Cove.Tool, among other software packages. The effectiveness of the proposed activities was measured with open-ended survey questions that were distributed to the students at the end of each semester. The results showed that students can develop self-confidence, occupational identity, problem-solving skills, and intellectual and cognitive understanding via these proposed activities. In addition, students indicated that the acquired skills in using the myriad software packages provided internship opportunities and assisted them in making better decisions about their future career paths.

Introduction

Continuously accepting new information and unifying it with existing knowledge is considered an essential feature of human learning (Thorisson, Bieger, Li & Wang, 2019). Students can use cumulative learning, as the cognitive process, for accumulating knowledge, skills, and abilities. These acquired skills and abilities will serve as building blocks for students' subsequent cognitive development. Further, it helps students meet the fast-changing demands of working in the complex contemporary world. Building cognitive ability is essential; therefore, educators must consider cumulative learning during course development activities to prepare students for lifelong learning (Heidari Matin, Eydgahi & Zareanshahraki, 2021). On the other hand, in authentic learning, educators use problem-based, case-based, and project-based pedagogies that offer students real-life examples of working practices (Bennet, Harper & Hedberg, 2002).

Engaging students in authentic learning activities adds a new layer to their prior experience (Herrington, Reeves, Oliver & Woo, (2004and enables cumulative learning (Maton, .(2009Due to the authentic nature of the studio courses ,at the heart of architecture/interior design education, cumulative learning could be considered one of the core concepts behind the learning process in architecture studios. There are two types of knowledge structures: hierarchical and horizontal. A hierarchical knowledge structure is a hierarchically organized, coherent, explicit, and systematically principled structure. While hierarchical knowledge structures are developed through new knowledge integration and incorporation of previous knowledge, horizontal knowledge structures focus on the accumulation and segmentation of knowledge (Maton, 2009; Maton, 2010).

In this current study, the integration of accumulation and segmentation knowledge structures were used to design a cumulative learning knowledge set that exposed students to different types of activities, based on both hierarchical and horizontal knowledge structures to promote cumulative learning. The goals of the activities were

- To introduce various software packages that are used in building simulation and design.
- To enable students to use and work with the same tools in various related courses.
- To enable students to explore all aspects and features of the tools they use.
- To enable students to characterize different views and properties of a building.
- To improve students' skills in evaluating the energy and lighting performance of a building.
- To engage students in analyzing the data obtained from the performance evaluation of a façade system with different characteristics and materials.
- To improve and advance student knowledge, understanding, and skills in using the same project in different courses.

A set of open-ended questions was created and given to the students at the end of each semester to determine the effectiveness of the proposed activities.

The Proposed Hand-on Activities

The proposed activities provided students with hands-on experience with 2D drafting, 3D modelling, and presenting and evaluating design performances. Through these activities, students were trained to utilize various high-demand software packages, including AutoCAD, Adobe Photoshop, SketchUp, Revit, Lumion, and Cove.Tool. Figure 1 shows the hierarchical relationship of the proposed multi-semester project and its corresponding activities for three courses. The first three activities focused on the design and development of a sustainable residential building. The next six activities used the output of previous activities for 2D drafting, 3D modeling, and advanced presentation of design , including photorealistic rendering, animation, and virtual reality (VR) 60panorama views. The last two activities used the architectural drawings options of the previous activities for determining building information modeling (BIM) and building performance evaluation. Figure 1 further illustrates that, after obtaining the results of building performance evaluation, there might be a need for an iterative process to modify and revise the building to improve the performance of the designed building. The following examples provide the details of each activity for the multi-semester course project.

Activity #01: <u>Client Interview</u>
In this set of activities, students identified a client, who represented the building resident with specific characteristics, such as having a sustainable lifestyle and caring about personal and societal environmental impacts. Then, students created a list of questions for an interview that would gather the necessary information for them as designers to develop a design concept for the entire project. In addition, students needed to specify how these questions could help them in specific design concepts, design strategies, and programming. Students recorded the information gathered during interviews by using sketches, diagrams, or words.

Activity #02: <u>Precedent Studies</u>
Considering the essential role of precedent studies in a design process, students had to select at least three related residential buildings located in cold and humid climate regions that were constructed based on sustainable strategies. Then, they analyzed and interpreted multiple aspects of precedent buildings using photographs, diagrams, doodles, and drawings. The design aspects that needed to be considered were building orientation and form, interior space sequences and arrangements, natural light penetration, natural air ventilation, interior circulation and exterior egress, number, shape, and direction of windows, finishing materials and furniture, and energy generation.

Activity #03: <u>Design Statement, Goals, Concepts, and Solutions</u>
After interpreting the information gathered via the client interview, the students considered the client's needs, preferences, and abilities for defining design statements. In addition, students got involved in exploring active or passive sustainable strategies in order to incorporate them into the design of the residential building. The utilized sustainable strategies consisted of passive heating, cooling, and ventilation strategies, which were considered along with design strategies such as optimum form, location, orientation, shading, and material selection. As a result, the final design statement consisted of design goals and design concepts that took into account both the client's needs and the students' acquired knowledge in a sustainable residential design.

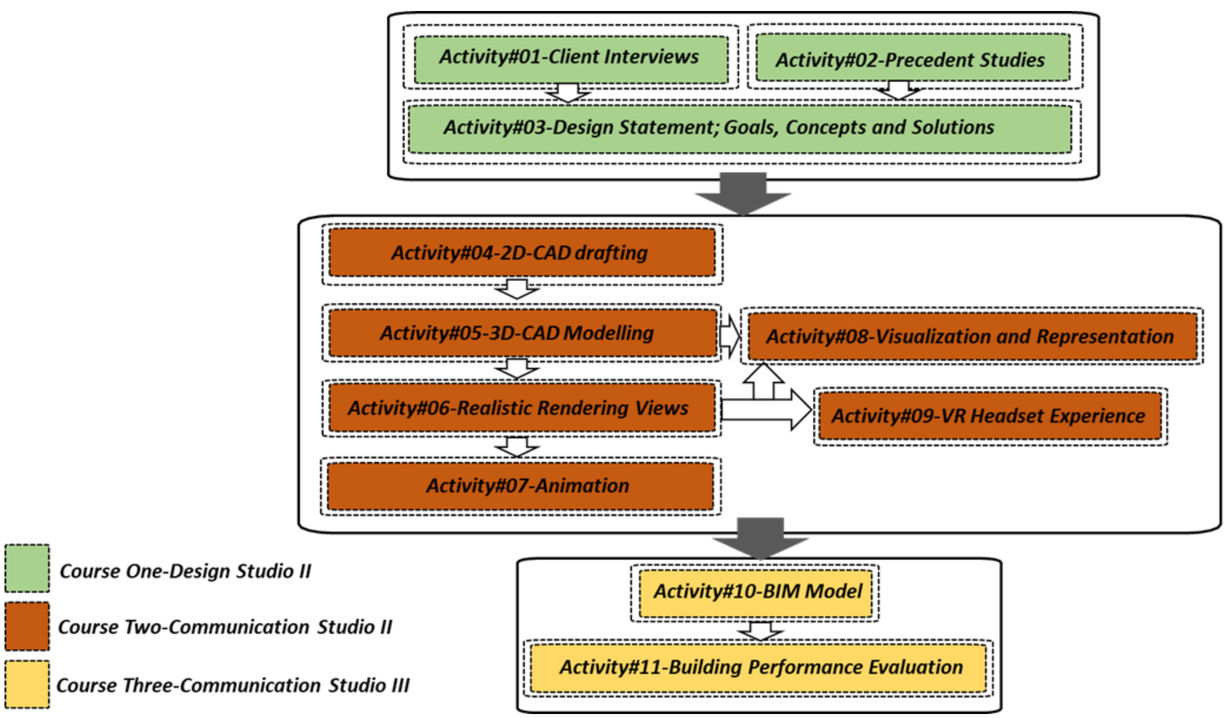


Figure 1. Relationship of the proposed activities for a multi-semester project in three courses.

Activity #04: <u>*2D CAD Drafting*</u>
In this set of activities, students used AutoCAD software to create 2D computer drafts by utilizing drawing and modifying tools, annotations and dimension tools, layer management techniques, sheet setting, and plotting setup options. In the Design Studio I course, students generated orthographic views of the sustainable residential buildings, such as floor plans, interior and exterior elevations, sections, and details. Figure 2 shows a 2D draft that was submitted by students as the result of this activity.

Activity #05: <u>*3D-CAD Modeling*</u>
In this set of activities, students were introduced to the application of SketchUp software in 3D modeling. A 3D model of sustainable residential buildings was simulated utilizing 2D and 3D modeling tools, such as solid tools, sandbox, styles, material, texture, effects, and warehouse. Since SketchUp software is compatible with AutoCAD, students learned how to transform 2D orthographic drawings to SketchUp 3D models of the sustainable residential building. Figure 3 shows the 3D model of a building created by students using SketchUp.

Activity #06: <u>*Realistic Rendering Views*</u>
To bring the students' designs to life, a new set of activities based on Lumion software was deployed. Lumion is an architectural visualization and rendering software package that enables students to create a world of context, capture the details of life, and convey realistic emotions and atmospheres. Thus, students can render realistic scenes without any specific rendering experience or background. Due to the compatibility of Lumion software with almost every 3D and CAD program, students learned to import the 3D model created in SketchUp into Lumion. In addition, in case of having computers with high computation power and advanced graphic cards, students were encouraged to use Lumion's real-time rendering feature called LiveSync to create a live connection between Lumion and SketchUp for their rendering activities and further iterative modification actions. After learning about scene navigation, landscape elements (terrain tools, trees, water, etc.), environmental features (wind, sun, rain/snow, sky, fire, etc.), lighting fixtures, 3D humans and animals, materials and furniture, students could generate different sets of realistic rendering views. Figures 4 a-b illustrate the interior and exterior perspective rendering views generated by students in this activity.

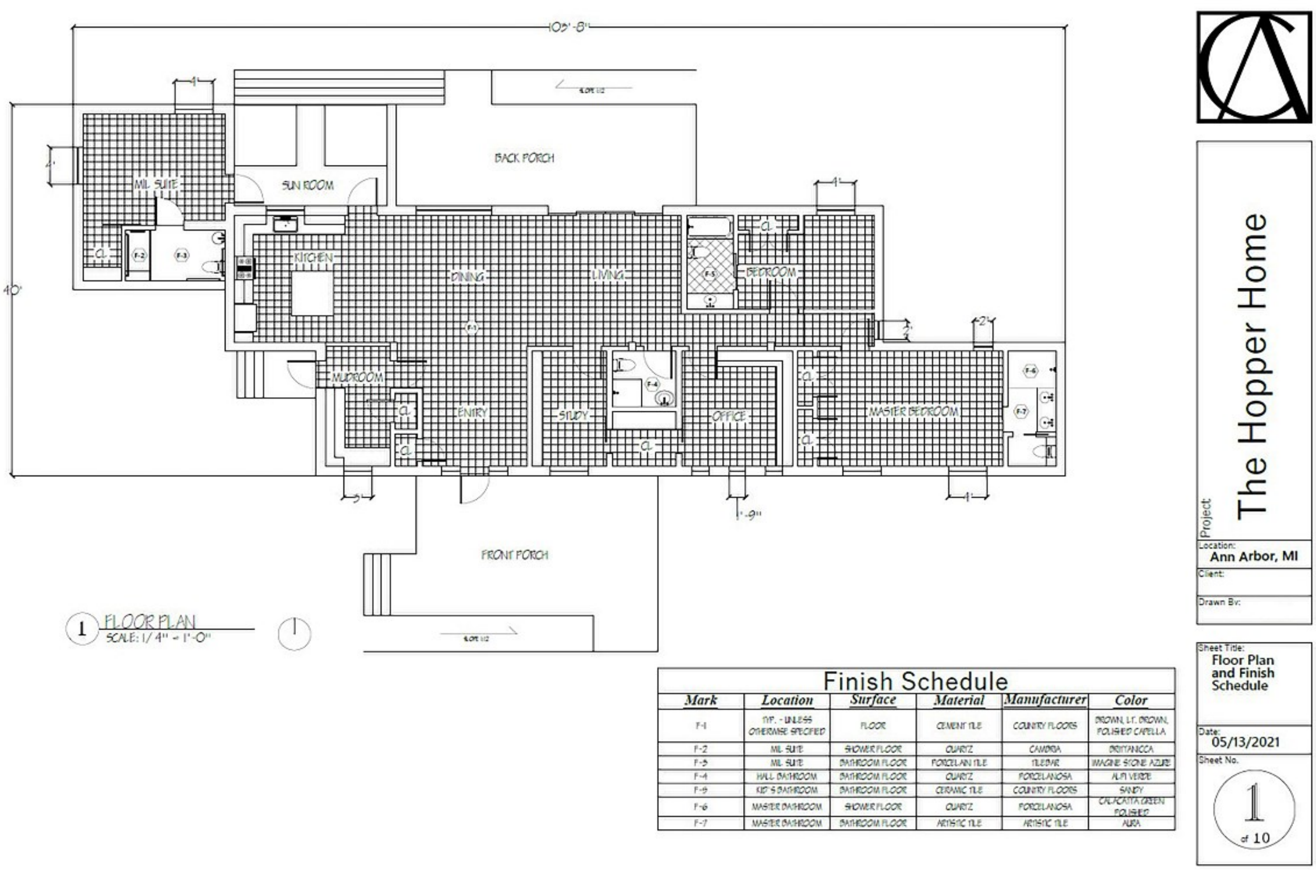


Figure 2. Example of a 2D draft submitted by students for activity #04.

Figure 3. Example of a 3D model submitted by students for activity #05.

(a) Interior perspective rendering.

(b) Exterior perspective rendering.

Figure 4. Examples of 3D models submitted by students for activity #06.

Activity #07: <u>*Animation*</u>
In this set of activities, students learned to create professional animations using Lumion software. After learning how to plan a storyboard, set camera locations, movements, and speeds, generate 3D human and animal motions, adjust animation effects, and add sound effects, students generated an animation that would bring life to the 3D model of a sustainable residential building.

Activity #08: <u>*Visualization and Representation*</u>
The focus of this set of activities was to make students familiar with the application of Adobe Photoshop software in architectural representation, visualization, and postproduction. The activities engaged students in applying different visual properties, such as color values, sharpness, saturation/hue, effects, and layer composition and adjustment. Students manipulated and elaborated the 2D images generated via AutoCAD and Lumion in order to deliver top-notch renderings and high-quality digital representations of their designs. Figure 5 shows how the students utilized Adobe photoshop for creating the high-quality digital representation of a sustainable residential building.

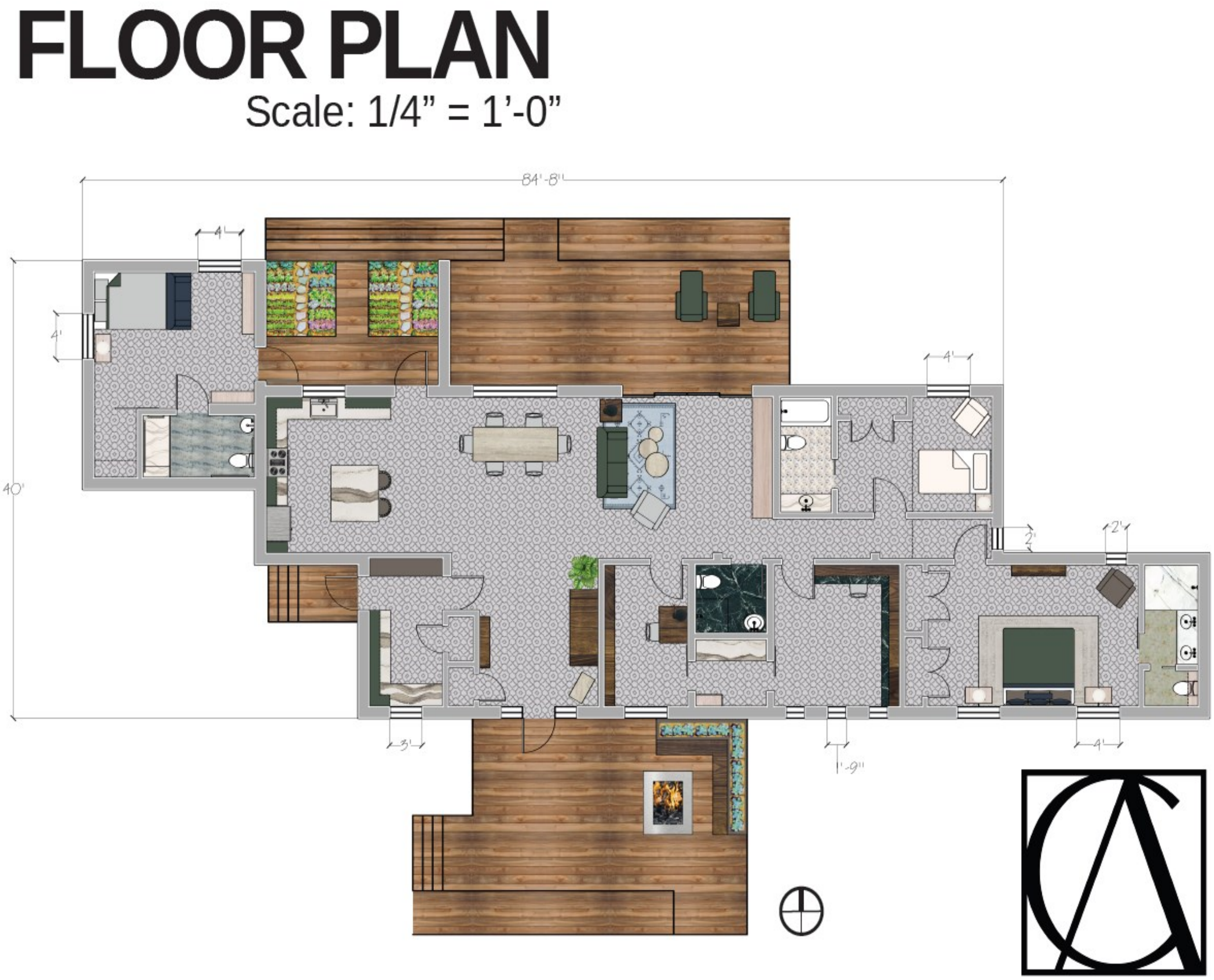


Figure 5. Example of a digital representation submitted by students for activity #08.

Activity #09: VR Headset Experience
Figures 6 a-b show how, in this activity, students learned how to generate 360° panorama views from interior and exterior views using Lumion and present them in a virtual reality headset. To do this, students were provided Oqolus Quest 2 headsets to evaluate the panorama views that were created by Lumion. Then, the students re-evaluated the design by changing factors of their design elements such as color and hue of interior spaces, material and texture, lights and shadows, furniture and accessories, size, and dimensions during their virtual tour of the simulated building. This provided an opportunity for the students to be involved in the iterative design process by modifying, revising, or changing their design elements. In addition, by using multiple headsets, the virtual tour experience with peers and instructor could be used for critique sessions, class presentations, collaborative teamwork, and communication with peers.

Activity #10: Building Information Modeling
During this set of activities, students were introduced to applications of BIM using Autodesk Revit. Figure 7 shows that, after learning about placing and adjusting building elements such as walls, floors, ceilings, roofs, doors, and windows, students simultaneously generated floor plans, elevations, sections, schedules, 2D and 3D views for the sustainable residential building. With emphasis on the application data/information in Revit, students were able to run cost estimation analyses for the buildings, considering quantities of building materials.

(a) 360° panorama views created by Lumion-Interior spaces.

(b) 360° panorama views created by Lumion-Interior and exterior spaces.

Figure 6. Examples of 3D models submitted by students for activity #09.

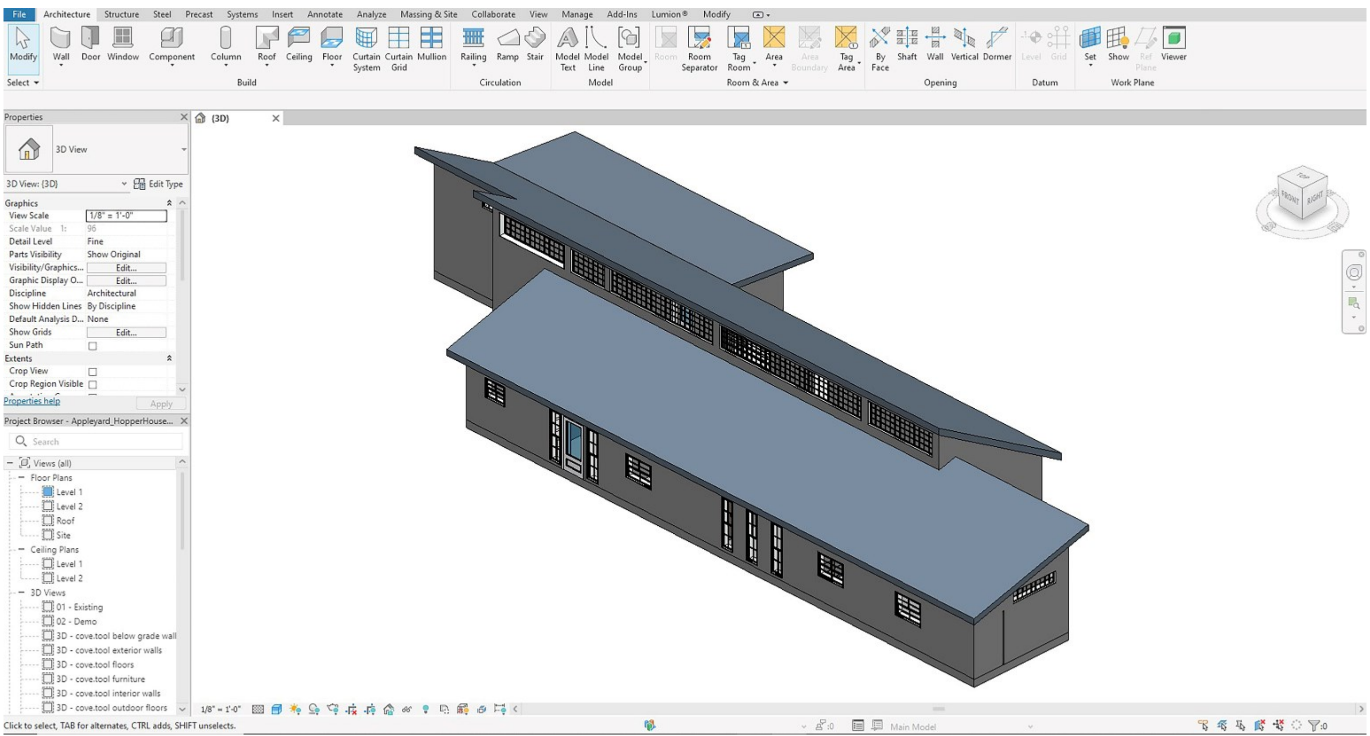
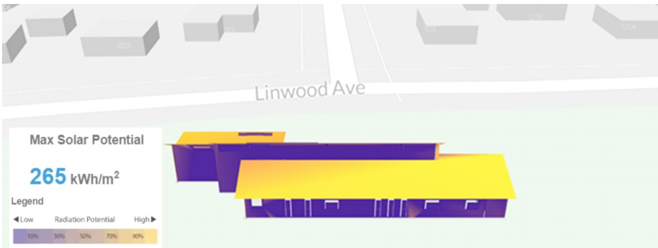


Figure 7. Example of a BIM model submitted by students for activity #10.

Activity #11: <u>*Performance Evaluation*</u>
In this set of activities, students used information on the building materials to analyze building performance. Students utilized Cove.Tool, which is a compatible app with Autodesk Revit for light and energy analysis of a sustainable residential building. After learning how to export the 3D model of the building from Revit into the Cove.Tool app, students explored different tools related to thermal comfort analysis, energy analysis, CO_2 emission elevation, and light analysis. Next, they chose a variable related to the building elements or materials, manipulated it multiple times, then recorded related changes in energy and light performance. Students then delivered a report about the selected variable, the manipulation process used for the experiment, the metrics that were utilized, and the results that were obtained. Figure 8(a) shows the maximum solar radiation on the exterior surfaces of the green residential building in the Cove.Tool; Figure 8(b) shows more the comprehensive parameters related to the EUI breakdown of the building and its corresponding benchmarks.



(a) Radiation 3D view.

(b) EUI breakdown of the building.

Figure 8. Example of a performance evaluation submitted by students for activity #11.

Implementation of the Proposed Activities

The proposed hands-on activities were implemented in three courses at the Gibbs College of Architecture at the University of Oklahoma: Design Studio II, Communication Studio II, and Communication Studio III. The courses were offered in consecutive academic semesters and involved both undergraduate and graduate students in the process of design, presentation/visualization, and evaluation of a sustainable residential building. The first three activities were used in the Design Studio II course. In this course, students were engaged in a design project focusing on a sustainable residential building. The course was developed with an emphasis on the issue of form, function, orientation, space, light, energy, and materials to meet assigned sustainability criteria.

Activities #4-9 were utilized in the Communication Studio II course. This course introduced students to computer applications in drafting, modeling, rendering, and presenting. The purpose of the course was to enable students to develop skills for utilizing the computer as an efficient and innovative 2D and 3D tool. This course was structured to introduce software applications such as AutoCAD Architecture, SketchUp, Lumion, and Photoshop. Upon successful completion of this course, students would be able to read and interpret various types of architectural construction drawings. Also, students learned how to produce computer-generated 2D architectural construction drawings and 3D models. Using advanced rendering tools, students would also be able to develop photorealistic presentation renderings, animations, and experience virtual reality technology.

The last two activities were implemented in the Communication Studio III course. This course introduced students to Autodesk Revit as the foundation of a larger process called building information modeling. By completing this course, students gained a robust understanding of Revit, its features, and capabilities, from the fundamentals to the most sophisticated and complex topics. Also, students were introduced to the concepts and terminology used in BIM and gained experience in creating an intelligent 3D model and extracting 2D drawings from it. In addition, since data could be generated, managed, stored, and exchanged in Revit, students could be involved in building performance modeling using Revit apps such as Cove.Tool. This course also trained students to utilize Cove.Tool for energy and light analyses.

For the multi-semester course project, students were supposed to design a one-story, single-family house with 2000 square feet of living space, three bedrooms, and two bathrooms in a newly developed neighborhood located in Ann Arbor, MI. It was assumed that the family living in the house would be interested in a sustainable lifestyle and promoting sustainability by purchasing energy-efficient appliances, growing their own garden, recycling household trash, and caring about wildlife and native species. Students were then asked to develop and present a complete design proposal for the project by using a formal client interview, personality observation, and conceptualization. The design proposal had to include the construction drawings, interior finishes, furniture/finishes, and a final proposal presentation.

Results and Evaluations

Activity #3 was designed with hierarchical relations to activities #1 and #2 for the Design Studio II course. The skills acquired in activities #1 and #2 can be considered knowledge blocks that are followed with cognitive development in activity #3. These activities were designed to educate students in the use of architectural technologies in drafting, modeling/visualizing, and animation of design ideas.

In the Communication Studio II course, the hierarchical relations of activities #4 to #7 address cumulative learning, as they integrate knowledge blocks that were learned in the previous course into new ones that they learn in this course. Activities #4 to #7 prepared students for real-life examples of work practices using AutoCAD, Adobe Photoshop, SketchUp, Revit, and Lumion. Activities #8 and #9 were designed for horizontal relations with activities #5 and #6, respectively. Horizontal relations between activities assist students in building new knowledge through the accumulation and segmentation of previous knowledge. In the third course, Communication Studio III, students learned about the application of BIM technology via Revit through activities #10 and #11. The hierarchical relations in activities #10 and #11 help students to incorporate their previous modeling knowledge with BIM knowledge and building performance analyses via Cove.Tool.

An open-ended interview questionnaire was developed to measure the effectiveness of the proposed hands-on activities in constructing new knowledge and connecting them to the students' previous experiences, skills, and abilities. The questionnaire focused on software self-efficacy, software anxiety, software confidence, and cumulative learning experience. Table 1 shows the survey questions. Thirty-four students in the Design Studio I, Communication Studio II, and Communication Studio III courses studying in the interior design program at both undergraduate and graduate levels participated in this survey. Figure 9 shows the age distribution (%) of the students who participated in this survey. About 52% of the students fell into the 10-20 age group; 35% fell into the 20-30 age group; 9% of the involved students were between 30-40 years of age; and, 4% of the students fell into the 60-70 age group.

Table 2 shows the statistical analysis of the survey responses. The highest standard deviation was observed for question number #8, while the responses to question #4 had the lowest standard deviation. This reveals that the majority of students agreed on the necessity of learning the communication software to improve their employment chances in the future. However, the answer to question #8 indicates that it is necessary to make some improvements and revise some of the design learning steps to enrich student learning experience. Figure 10 shows that, for the survey result for question #1, using the proposed hands-on activities can increase student confidence, since 88.24% of the students agreed with this statement. Figure 11 shows that, for the responses to question #2, 82.35% of the students declared that their software anxiety decreased by learning multiple design software packages in these continuous courses.

On average, 91.18% of the students responding to question #3 indicated that utilizing multiple software packages during the classes increased their software self-efficacy. In response to question #4, 82% of the students indicated that applying advanced communication technologies in these courses could increase their employment/summer internship chances. Figure 12 shows that, for the responses to question #5, %88.24 of the students were in support of the statement that learning integration of design software in continuous semesters helped them build knowledge blocks continuously and unify them with their existing knowledge.

Table 1. Survey questions.

#1	I feel confident about my design software skill after completing my design project using multiple software in these classes.
#2	I believe learning the combination of software in this class decreased my software anxiety.
#3	I believe implementing multiple software learned during these classes increased my software self-efficacy.
#4	I believe applying advanced communication technologies in these courses could increase my employment/summer internship chances.
#5	I believe learning integration of design software in continuous semesters helped students to build knowledge blocks continuously and unify it with their existing knowledge.
#6	I think learning the integration of design software in continuous semesters improved my cognitive abilities, critical thinking, and problem-solving skills.
#7	I think learning integrated design software improves my course engagement and provides the background for me to be capable of learning multiple things both concurrently and consecutively.
#8	I think the proposed hands-on activities assisted me in learning and gaining new knowledge incrementally without catastrophic forgetting or damaging my existing skills in this class.

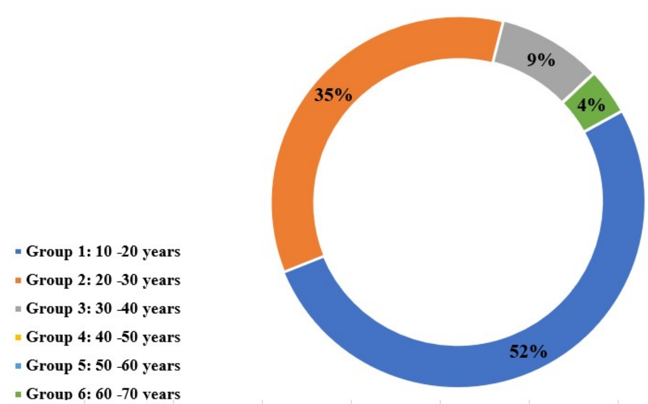


Figure 9. The age distribution (%) of the students who participated in the survey.

Table 2. Statistical analysis of the questions.

No.	Mini-mum	Maxi-mum	Mean	Std Deviation	Variance	Count
#1	1	5	4.21	0.9	0.81	34
#2	1	5	4.24	0.97	0.94	34
#3	1	5	4.21	0.9	0.81	34
#4	3	5	4.47	0.78	0.6	34
#5	2	5	4.29	0.82	0.68	34
#6	1	5	4.03	1.01	1.03	34
#7	1	5	4.09	1.01	1.02	34
#8	1	5	3.91	1.12	1.26	34

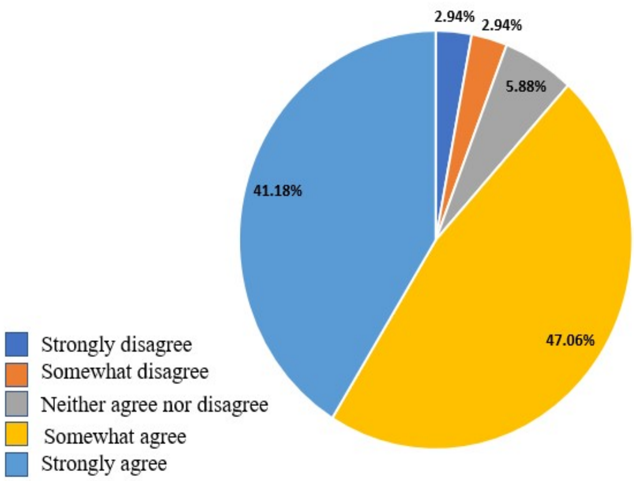


Figure 10. Students' confidence rate.

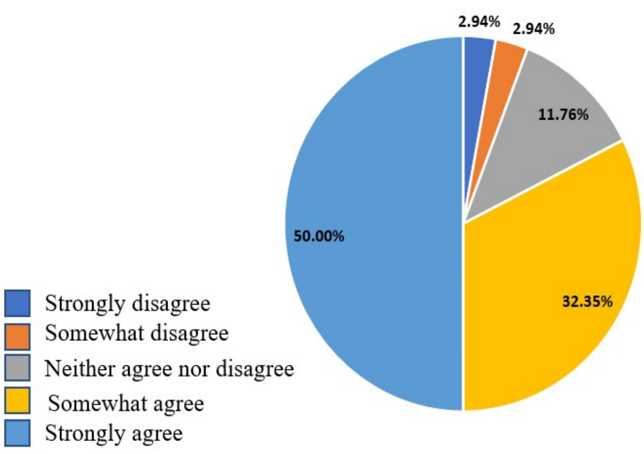


Figure 11. Students' anxiety rate.

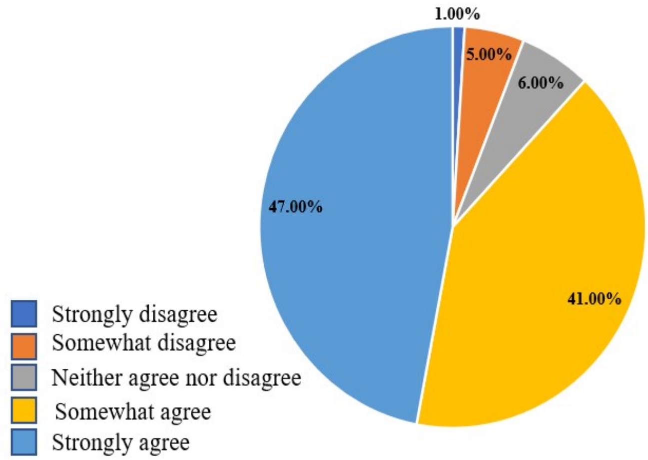


Figure 12. Student opinions on the impact of using integrated software.

In response to question #6, 83.05% of the students declared that learning integration of design software in continuous semesters improved their cognitive abilities, critical thinking, and problem-solving skills (strongly agree = 35.29%, somewhat agree = 47.06%, neither agree nor disagree = 5.88%, somewhat disagree = 8.82%, disagree = 2.94%). The result of the students' responses to question #7 showed that 73.53% agreed (strongly agree = 44.12%, somewhat agree = 29.41%, neither agree nor disagree = 20.59%, somewhat disagree = 2.94%). In response to question #8, students declared that the proposed hands-on activities assisted them in learning and gaining new knowledge incrementally without catastrophic memory loss or having deleterious effects on their existing skills in this class, with 73.53% in agreement (strongly agree = 35.29%, somewhat agree = 38.24%, neither agree nor disagree = 14.71%, somewhat disagree = 5.88%, disagree = 5.88%). Based on the survey results, the proposed activities assisted students in developing their self-confidence, occupational identity, problem-solving skills, and intellectual cognitive skills that will be very useful for their future careers.

Conclusions

In this paper, the authors presented a set of hands-on activities suitable for both graduate and undergraduate students in the architecture and interior design fields. The proposed hands-on activities were tested in three continuous courses in the Interior Design Division at the Gibbs College of Architecture at the University of Oklahoma: Communication Studio II, Communication Studio III, and graduate Studio II. The collected student feedback showed that students were more engaged in the activities that utilized software and were less hesitant to initiate a project using various software packages. This indicates that students became more confident and ready to deliver required outcomes. These activities also assisted students in forming unified knowledge by using different skills and integrating them into one project. As a result, students were able to identify their weaknesses, abilities, and areas of interest. Furthermore, students indicated that, after having these activities, they were able to better understand steps of a project, which means that they paid more attention to details and to the overall requirements of the project. It was also observed that the level of the students' confidence in their knowledge improved and they explored more possible options without having any direct help from the instructor. Some students mentioned that the acquired skills in using multiple software packages provided internship opportunities for them and help them to make better decisions about their future career paths.

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Biographies

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Optimization of the Batch Manufacturing Process for Three-cell and Five-cell

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Abstract

Charger Industries (Ltd.) designs and manufactures battery power packs for the oil and gas wireline industry. Two of their products were customer-designed and have tighter tolerance requirements than other products in their product line. Additional costs are associated with the procedures needed to meet these more stringent requirements. One process requires the use of a jig when applying heat-shrink material to the battery power pack and is the source of high rebuild percentages. It is this process that is the focus of this paper. In this study, the authors performed a design review and quantitative tests. A series of 56 test builds of the heat-shrink application process were performed. Each test-build varied key elements of the process to allow insight into each element's impact on repeatability in achieving target lengths and reduction in rebuilds.

From this study, the authors identified four key recommendations: 1) use of a nozzle for the heat gun at maximum temperature for improved heat transfer; 2) continued use of jigs for achieving target manufacturing lengths—the post-heat-shrink application time-in-jig should be limited to 10 minutes; 3) change the target length measurement by +0.010 inch for the initial tolerance specification window to account for overnight shrinkage; 4) implement the use of an oven for controlled application of heat to heat-shrink material prior to assembly installation. Implementation of these recommendations will provide an estimated 71% operational cost savings to the heat-shrink portion of the manufacturing process. An additional 5% in savings may be achieved when accounting for a reduction in rebuilds. Other businesses could learn from this study and conduct a similar investigation into their current process and harvest considerable financial benefits depending on their scales.

Introduction

Charger Industries is an industry-leading battery power pack manufacturer for the MWD (Measurement-While-Drilling) tools sector of the oil and gas industry. These products provide the power for the electronics used in the high-pressure and high-temperature (150–200°C) environments for the tools needed during the well-drilling process downhole. Of the power pack products manufactured at the Houston location, one pair of products (three-cell and five-cell power pack assemblies) was customer designed. These designs have tighter tolerance specifications than other products made by Charger Industries and require additional manufacturing steps to meet specifications.

These products require a jig during manufacture to compress the power pack to the specified design length. The power pack is then encased in heat-shrink material for protection and to maintain the compressed length achieved by the jig and re-establish axial alignment due to the bowing that occurs during compression. Figure 1 illustrates this process.

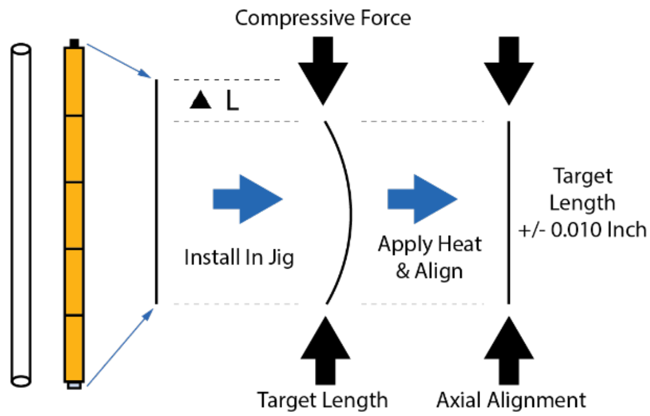

Figure 1. Illustration of the compression of the battery pack to achieve the target length and axial alignment maintained by heat-shrink material.

Efficient assembly using this process is very technician-specific, due to the various techniques used by each technician when applying heat to the heat-shrink material. These technique variations may include, but are not limited to, the following:

1. Distance of the heat gun from the heat-shrink material.
2. Duration of heat application.
3. Location and sequence of heat application along the power pack: a) top-to-bottom of the power pack, and b) center-to-top / center-to-bottom of the power pack.

Inconsistent build quality is a result. Breakdown and rebuilds are common. Charger Industries is asking for the current manufacturing process to be investigated. The goal of this study was to identify and implement tools and procedures that could increase fit repeatability, foolproof the manufacturing process, and positively impact product economics. This current study was broken down into three components: A review of the manufacturing process during the heat-shrink application process; a design evaluation of the three-cell and five-cell power packs; and, recommendations.

The manufacturing process review would capture the current state of the manufacturing process and document key areas of opportunity, based on project metrics ranging from consistency and time to meet target length tolerance specifications to determining the instances and time to rebuild the battery power packs. Initial indications were that the jig apparatus and application of the heat-shrink material would be a key focus in this part of the investigation. This area of investigation is in control of Charger Industries and recommendations generated from these findings were intended to show the most improvement in the process and economic impact.

The power pack design review focused on the component items of the power pack itself. The authors attempted to confirm the specification tolerance requirements and thought process for the components' specifications, but the customer primarily controls this area of investigation. In this paper, the authors conclude with recommendations from the investigations. Improvements to product output quality metrics and documentation of rebuild instances were recorded and evaluated for the economic impact on Charger Industries.

Literature Review

In addressing the manufacturing improvements of the advanced technologies of the MWD power packs in this project, the authors will propose improvements for processes that may not have complete documentation. Bengston (2010) acknowledges that "many manufacturing processes have evolved or matured in the dark, and are based on anecdotal information, unrecorded assumptions and tribal knowledge." Process management improvements will document and capture best practices (i.e., tribal knowledge) related to the manufacturing of these three- and five-cell power packs. By simply being aware of the potential hidden process opportunities, the manufacturing steps can be better captured to document, record, and pass along those learnings to future manufacturing teams. Establishing a fixed process for manufacturing, a standard work for the 3-cell and 5-cell power pack assemblies will be established.

Sundar, Balaji and Kumar (2014) describe standard work as "the safest and most effective method to carry out a job in the shortest repeatable time as a result of utilization of resources." Establishing standard work results in standard operating procedures (SOP) that document processes and sequences of work. As a component of lean manufacturing, these small steps in the organization of the manufacturing processes lead to baselines where performance can be measured and adjustments for improvement can be made. The use of the jig in this project was necessary, due to a tolerance requirement of the design. Hu and Xiong (2005) established that, as tolerance standards increase for a given product, manufacturing costs also increase. In this current study, the authors evaluated product design and looked for those decisions that determine the tolerance requirements that would require added processes. Design insights, in combination with manufacturing considerations, may allow for less strict tolerance requirements, if the reasons for those requirements are explored further. Kraus and Ryan (1988) described the general manufacturing process of heat-shrink material as follows:

> In manufacturing heat-shrinkable products, plastic is formed into tubing… before it is irradiated. The material is then heated enough to melt its crystal structure, stretched, and allowed to cool in this new form. The crystals reappear to hold the product in its expanded shape. When the end user heats the tubing …, the crystals melt again, allowing the cross links to pull the polymer back to its original unexpanded shape. As it cools, the crystals return to preserve the recovered form. (p. 31)

Fluorinated ethylene propylene (FEP) is the heat-shrink material used to protect and maintain the length of the three- and five-cell battery power packs in this project. Kili (2014) described FEP is a "random perfluonated copolymer of tetrafluoroethylene (TFE) and hexafluoropropylene (HFP) monomers." In this current study, the authors evaluated the process of final application of the FEP heat-shrink material, paying particular attention to improving consistency in achieving the recovered state of the material.

Methodology

This project's primary focus was on process investigations that most impact the length tolerance specification of the power pack assemblies. All quantitative physical testing investigations of this study focused on the five-cell power pack to reduce the number of iterations of testing. Deductions for this portion of the study were extended to the three -cell power pack by extrapolation. Qualitative studies are applicable to both three-cell and five-cell power packs. The investigation was broken down into three sections.

1. Areas controlled by the contractor—Charger Industries
2. Areas controlled by the customer
3. Heat-shrink material application review

Areas controlled by Charger Industries include the physical process of assembly of the power pack products. The area of the process impacting the overall length of the final assembly is the use of the power pack jig and the application of the heat-shrink material. The test procedure of the heat-shrink application entails various structured applications of the heat-shrink material to the same four "dummy" five-cell power packs. The structured heat-application scenarios entail four primary categories with two options each and one singular investigation. Twenty testing scenarios are the result. Only 16 conditions can be evaluated, because the use of the nozzle with the heat gun requires the use of the jig and precludes any pre-heat application scenarios.

Data Analysis

Statistics related to data collection include the following:

- Total five-cell power pack builds: 56
- Unique test configurations: 18
- Recorded data points: 631

Testing included the documentation of the heat-shrink application process of the original technician for historical reference. This data set was included in the data analysis discussion. Additionally, the dummy cells provided for testing came in two configurations. One set was empty and hollow but fully enclosed, and the other set was filled with sand. These two configurations allowed for a review of the role of heat retention of the cells. For this current study, five-cell power packs were used for all the “dummy” cell configurations. The primary focus of this study was to capture the impact of various techniques of applying heat-shrink material to the power pack product. Collected data were compiled in Appendix A – Collected Data. If the data are reviewed in a whisker plot, it is easy to see that the two types of dummy cells (hollow versus sand-filled) had different performance. Figure 2 captures the lengths of the different configurations right after the heat-shrink application and the length change that occurred overnight.

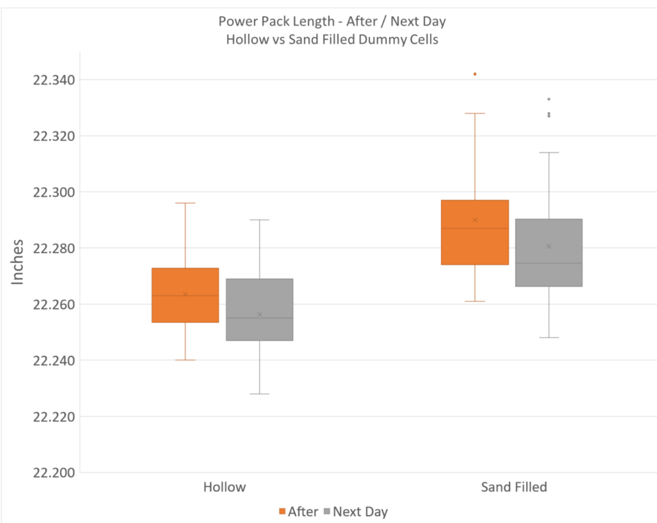

Figure 2. Length of test power packs with hollow and sand-filled dummy cells.

The material in the cells that is filled with sand was determined to be absorbing an impactful portion of the heat being transferred during this process. This process resulted in the hollow dummy power packs having more overall length change than the sand-filled dummy power packs and allowed more recovery of the heat-shrink material at the time of heat application. Because the actual battery cells of in the production of the power packs were filled with lithium and were not hollow, it was concluded that the performance properties of interest would be most reflected in data from the dummy power packs made with the sand-filled cells. For this reason, the remainder of the analysis was in the review of data from the dummy power packs made from the sand-filled cells. The application of the heat-shrink tubing resulted in a reduction in the overall length of the assembly. The historical data set was the length change achieved by the technician that had historically performed this process. Please note that this technician’s process was unbounded by testing constraints to capture the process and document overall efficiency as historically performed. The achievement of reaching the target length for the product requirements required substantial time compared to the planned testing procedure of this investigation and will be discussed later in this paper. Figures 3 and 4 are whisker plots comparing heat gun temperature (high and low), and the use of the jig while heating (in-jig and no-jig).

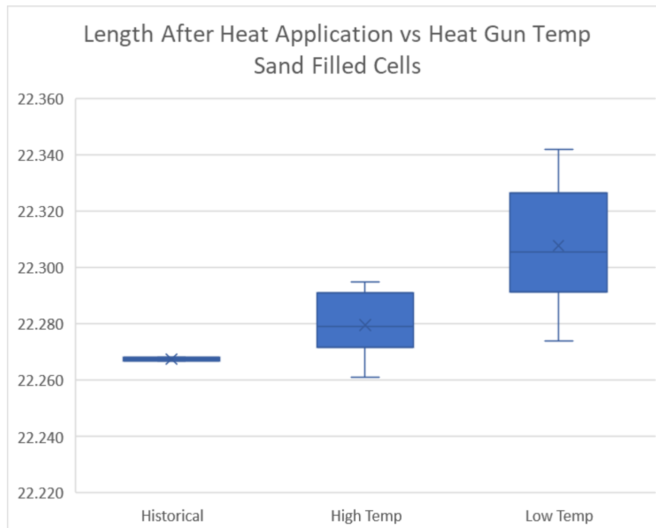

Figure 3. Length of test power packs – heat gun temperature.

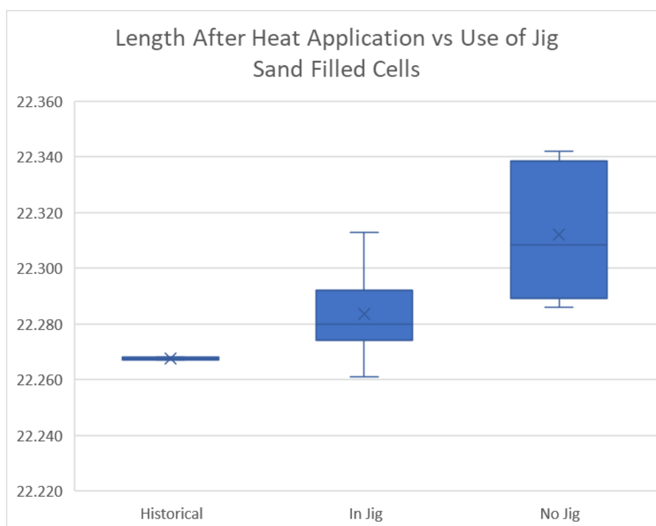

Figure 4. Length of test power packs – use of jig during heating.

Figure 5 (heat gun temp) and Figure 6 (use of jig during heating) each show data sets that are quite significant in the difference in length change. The higher temperature setting of the heat gun had a larger impact on the length change of the power pack, as did the use of the jig. Each resulted in better targeted results for the power pack. The heat gun temperature and use of the jig also showed differences in the impact on the overnight length change of the power pack assembly. The average overnight change was -0.012 inch for the high-temperature setting of the heat gun versus -0.008 inch for the low-temperature setting. The average overnight change was -0.012 inch when a jig was used during heating versus -0.009 inch when no jig was used. The difference is approximately 25%.

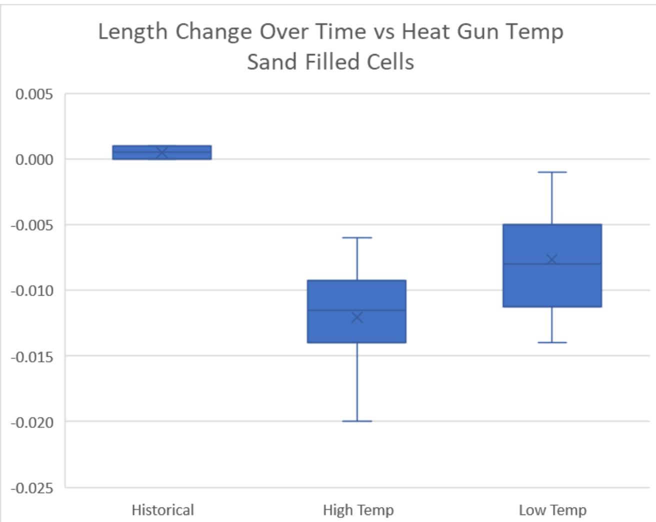

Figure 5. Length of overnight change of test power packs – heat gun temperature.

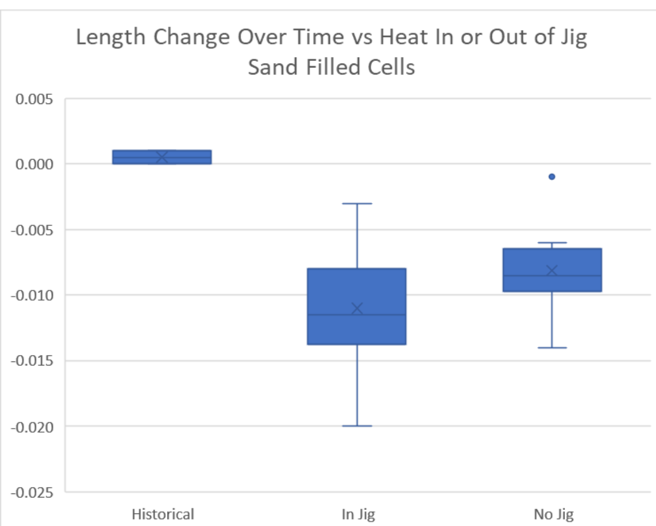

Figure 6. Length of overnight change of test power packs – use of jig.

The average overnight change in length approximated 50% of the tolerance window for the entire assembly. This information will be valuable in establishing pre-QC target lengths and may significantly impact rebuild percentages of the assemblies, should this shrinkage be accommodated in the manufacturing processes. Figure 7 presents the results of the investigation of the use of an oven to put the heat-shrink material through a controlled heat cycle prior to application on the power pack. Two controlled conditions were tested, one with the heat-shrink in an oven at 55°C for 25 minutes and the other at the same temperature for 1 hour. The figure also shows that the controlled heating in the oven contributed to a much tighter spread of lengths achieved both right after heat application with the heat gun and over time with the measured length the next day. The 60-minute controlled heat cycle in the oven of the heat-shrink material prior to installation on the power pack shows the possibility of increased process repeatability in achieving target lengths that are not indicated in any other test configuration.

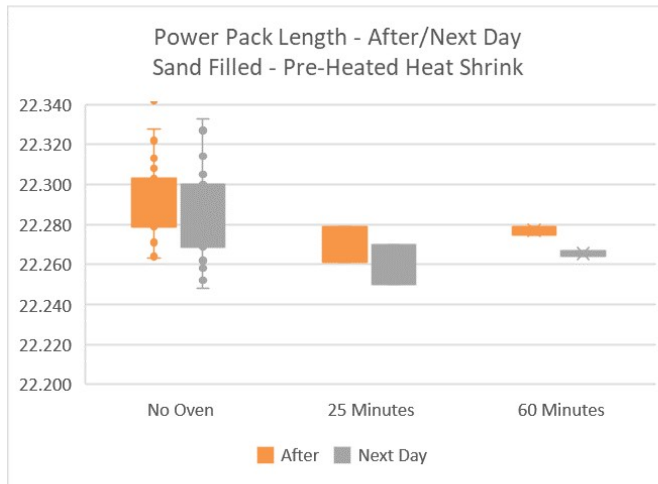

Figure 7. Length change after / next day– controlled heat.

The total time recorded for each application was from the time it was placed in the jig initially until the next assembly was placed in the jig. This was intended to simulate a continuous cycle under production. Power packs assembled by the historical process achieved assembly lengths within tolerances but came at the expense of time, taking an average of 55 minutes to achieve. For the testing of the matrix scenarios, heat was applied for the time necessary—appropriate for the application—and the power pack was left in the jig for 10 minutes before removal and measurement. This approach allowed for processing a unit every 15 minutes using one jig. The following conclusions and recommendations can be made.

1. Direction of heat application to the heat-shrink material showed no impact on the repeatability of achieving target length or reducing overnight change in length to the battery packs. Conclusion: No influence on the output.

2. Use of the nozzle is open to interpretation. It was thought that it would add a level of control to the heat -application process, beyond what could be done without the nozzle, and might assist in equalizing overall performance from one technician to another. However, for a trained technician, no influence was captured in the data set. Conclusion: The authors recommend use of a heat gun nozzle to normalize performance among technicians.
3. Use of the jig while heating the heat shrink demonstrated a direct correlation to achieving target length. The overnight length change was found to consistently achieve an additional length change of approximately -0.010 inch. Conclusion: The authors recommend use of jig.
4. Use of a high heat setting of the heat gun while heating the heat-shrink material had a better correlation to achieving target length. The overnight length change was found to consistently achieve an additional length change of approximately -0.010 inch. Conclusion: The authors recommend use of a high heat setting on the heat gun.
5. The use of an oven for a controlled heat application cycle to the heat-shrink material prior to assembly of the battery pack demonstrated significant influence on achieving repeatable target length. The overnight length changes also showed consistency of -0.010 inch. Conclusion: The authors recommend implementation of a pre-heating cycle of the heat-shrink material in a heat-controlled oven at 55°C for one hour.

The target length of the assembly to pass final quality control was 22.260 inches +/- 0.010 inch. The preceding testing documented a consistent change in length overnight of approximately -0.010 inch. To accommodate this overnight change, the target length for the assembly should be between 22.260 to 22.280 inches, after the initial heat cycle. Any efforts to improve the current jig apparatus should focus on the following:

1. Improvement in the speed of securing the power pack assembly into the jig. The initial setup used wing nuts with integral threaded shafts to attach a compression plate to a series of columns in order to establish the target length of the battery pack under compression. Figure 8 shows that improvements during testing were implemented by securing the threaded shafts to the columns instead of the wing nuts and were successful in speeding up the process. A camlock-type securing application should be investigated.
2. The current design allowed for this application when accommodating the use of a nozzle on the heat gun, although more space may allow for more freedom of movement and better heat distribution.
3. Consideration for allowing more than one power pack in the jig. This should be determined by the sequence of full tightening of the jig on the power pack. The testing for this current study used a two-step approach: Light fastening during initial heating and full tightening during the 10-minute static condition. A two-step approach in the process may make the jig too complex.
4. Favoring multiple simple jigs over a complex single jig that manages many power packs at once.

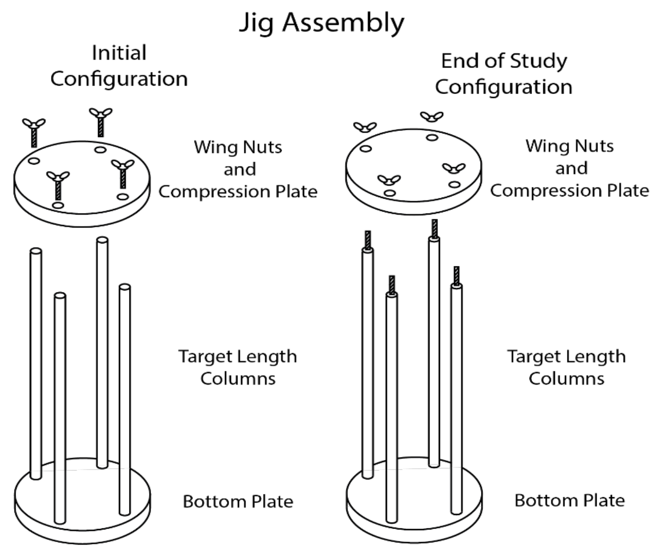

Figure 8. Wing nut assembly configuration. Initial and end of study.

Areas controlled by the customer include the actual design of the power pack products. The authors, during this current project, reviewed the power pack components for design and purpose and evaluation of the tolerance requirements' justification for the application.

Data Analysis

In both the three-cell and five-cell power pack designs, there were five primary components that made up the overall length of the assembly, which needed to be within +/- 0.010-inch tolerance specification. Table 1 lists these items, the lengths, tolerances, and the count for each power pack assembly.

Table 1. Power pack components contributing to target length.

Part Name	Length	Tolerance	3-Cell Power Pack	5-Cell Power Pack
	Inch	+/-	Part Count	Part Count
Top End	0.995	0.005	1	1
O-Ring, Silicon	0.139	0.004	4	6
Washer, Plastic	0.062	0.007	4	6
Power Cell	3.850	0.050	3	5
Bottom End	0.998	0.0025	1	1

In a review of the target length, it should be noted that the native length of the power pack was longer than the target length after the heat shrink was applied. Analysis of the above table shows that the five-cell power pack length, before application of the heat shrink, was 22.449 inches. The length of the target for the assembly after the heat-shrink application was 22.260 inches +/- 0.010 inch. The overall change in length that had to be achieved was approximately 0.189 inch. This compression was entirely accommodated by the properties of the silicon O-rings. All other components were fixed in function and/or material structures. The top end, for instance, was stainless steel and had fixed-length properties.

Although consultation with the customer would have been advantageous, the assembly testing previously reviewed provided confidence that consistent target lengths can be achieved through manufacturing adjustments, as noted in the previous section, and no design changes of the power pack would be necessary to reach the project objective. The purpose of the heat-shrink material application review was to better understand its use and confirm best practices for the application. As the test matrix was systematically completed, rules of thumb presented themselves. Many of them were anecdotal at the beginning of the project but were confirmed within the data. One understanding was that the power packs would change in length after they were set aside for QC. This was officially documented in the testing. As much as 0.010 inch of shrinkage in the total length of the power pack was routinely observed. The technician should make accommodations for this phenomenon.

More significantly, the total thermal energy applied was important to the recovery process of the heat-shrink material. If the applied heat were varied and inconsistent across the entire length of the heat-shrink material, a wide variety of responses would be observed. This is evident in Figure 7, where the handheld application had a wide spread of achieved lengths, while the use of an oven in a controlled cycle of thermal exposure promoted tighter responses in overall achieved target length. In the latter case, perhaps 60-75% of the thermal energy came from the time in the oven, while the remaining 25-40% was achieved through the application of the heat gun. This contrasts with the 100% use of the heat gun. The heat cycle in the oven reduced the overall total thermal heat transfer variability of the process.

Return on Investment

In this study, the authors also evaluated the monetary impact of implementation by breaking it down into two parts. The first was to characterize the historical rebuild percentages and establish an average annual order and rebuild volumes. The second part was to establish the potential cost savings of implementation of the recommendations presented in this paper, given the historical average annual order volumes and an estimate of rebuild costs.

This product family of three-cell and five-cell power packs has been in production since August of 2018. Initial product runs were of the three-cell model followed by the five-cell model in August of 2019. Table 2 shows the total historical rebuild percentages for each product and the rebuilds of the product family as a whole.

Table 2. Historic and average annual build and rebuild estimate.

	Historical Build and Rebuild Percentages			
	August 2018 – July 2021			
	3-Cell Power Pack	5-Cell Power Pack	Total Power Packs	Annual Avg
Total Units Ordered	772	400	1172	185
Total Units Rebuilt	151	63	214	34
Percent Rebuild	20%	16%	18%	18%

The test matrix documented opportunities set forth in the paper's recommendations. These recommendations impact two areas of interest in the economic evaluation. By adjusting the target length of initial heat-shrink application by -0.010 inch documented in the test matrix, the 18% rebuild percentage could be drastically improved. This shrinkage was not considered previously and has been a recent cause of build rejections, due to shrinking outside of the tolerance specifications.

Cost Analysis and Savings Potential

Table 3 presents the annual potential cost savings, where the rebuild reduction and process improvement estimates are combined. By implementing only the procedural changes, the cost per unit for the heat-shrink application improves by 71% over the historical process, requiring 50+ minutes on average. With the addition of a second jig unit, the manufacturing cost per unit improves to 81%. When evaluated on an annual basis, and assuming proper implementation of the -0.010-inch additional change in length overnight, the cost savings would be $11,284 annually, should a second jig not be implemented. A cost savings potential of $12,436 is possible if a second jig is available. These are 76% and 84% reductions in heat-shrink annual processing costs, respectively.

Notes regarding the preparation of a battery power pack for rebuild following failure to meet length specifications: length standards are confirmed before proceeding to final production; failure requires replacement of the heat-shrink material; removal of the heat-shrink material takes less than five minutes; the process to reattach the heat-shrink material is performed as described in this paper. For this reason, the improvements to the heat-shrink application process were the focus of the economic analysis.

Table 3. Processing cost evaluation.

Heat Shrink Process Cost Evaluation - Average Annual Build				
	Historical	Process Improvements Only	Addition of the 2^{nd} Jig	
Cost of Heat-Shrink Material	$5.60	$5.60	$5.60	$/ft
Length of Heat-Shrink Material per Power Pack	2	2	2	ft
Cost of Heat-Shrink Material per Power Pack	$11.20	$11.20	$11.20	Material Cost per Unit
Avg Historical Process Time	0.875	0.250	0.167	hr/unit
Facility Manufacturing Cost per Hour	$75.00	$75.00	$75.00	$/hr
Heat Shrink Facility Manufacturing Cost	$65.63	$18.75	$12.53	$/unit
Manufacturing Cost Improvement		71%	81%	
Average Annual Builds	185	185	185	
Average Annual Build Costs	$12,141	$3,469	$2,317	
Rebuilds (18% Historical)	34	0	0	
Rebuild Costs	$2,612	$0.00	$0.00	
Total Annual Heat-Shrink Material Processing Cost	$14,753	$3,469	$2,317	$/Year
Projected Annual Cost Reduction Savings		$11,284	$12,436	$/Year
Annual Cost Savings for the Heat Shrink Process		76%	84%	

Recommendations and Conclusions

This project began with the objective of evaluating the use of a jig during the production of three-cell and five-cell power packs to meet heightened tolerance specifications relative to other products. It was believed that, through the improvement of the jig, the process could be streamlined and rebuild percentages could be reduced for this product set. Initial evaluations of the process established an outline of investigation, resulting in a test matrix that focused on the application of heat-shrink material onto the power pack assemblies. The execution of the test matrix was heavily focused on the use and application of the jig apparatus in question. The authors make the following recommendations for immediate effects in the next build cycle:

1) Use of a nozzle for the heat gun at maximum temperature for improved heat transfer.
2) Continued use of a jig, either in its current form or with improved ease-of-use modifications, as outlined earlier in this paper (see Figure 8). Maintain a restrained condition in the jig for 10 minutes after application of the heat gun.
3) Change the target length measurement window by +0.010 inch (22.260 to 22.280 inches) for the initial tolerance specification window when measuring for the length of the power pack but just after heat-shrink application. This will account for the overnight shrinkage of the power pack assembly and eliminate rebuilds because of missing the final tolerance specifications due to insufficient length.
4) Implement an oven for controlled application of heat to the heat-shrink material prior to assembly. A heat cycle of 1 hour at 55°C was sufficient to improve target length objectives during testing.

These procedural changes utilize resources already available in the manufacturing facility and offer a 76% annual financial return over the process currently in place. As noted above, investment in a second jig may only be necessary if the average annual build requirements significantly improve over the volumes evaluated in this paper. As for general knowledge of the heat-shrink material, every effort should be made to ensure that the total thermal energy applied to the material is consistent across its entire length. Improvement on this front in this application was through the use of a nozzle on the heat gun, using the highest temperature setting of the heat gun, and the use of an oven for a prescribed period of time along with a temperature to accomplish a portion of the recovery process.

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Developing Cost-Effective Approaches to Lab Equipment for Applied Engineering Programs

Jake Hildebrant, Murray State University

Abstract

Many variables have led public universities and community colleges in the United States to cut operating budgets since the 2008 recession, such as weakening state budgets, underfunded pensions, and the Coronavirus. Applied engineering programs often require expensive training equipment and software to give their students the industrial experience they need once they graduate. In this study, the author conducted a project to encourage student engagement, while supplying much-needed industrial applications through laboratory trainers. Examples are encouraging industry equipment donations and assigning students to utilize the donations to create laboratory equipment. In this paper, the author presents specific examples of equipment created by students and the results of the students' opinions of the projects. Students learned to design and create a budget, manage a project, and commission the trainer, while saving colleges valuable operating funds. This current project used an industrial instrumentation trainer built by students in an electromechanical engineering technology program.

Introduction: The Barrier of Expensive Trainers with Reduced Budgets

As tuition has drastically increased, operating budgets for universities and community colleges have decreased over the last few years. According to the Center for Budget and Policy Priorities (Mitchell & Materson, 2017), state funding for public two- and four-year colleges in the 2017 school year was $9 billion below the 2008 level, when adjusted for inflation. Because of this budget cut, 44 states spent less per student in 2017 than in 2008. The exceptions were Indiana, Montana, Nebraska, North Dakota, and Wyoming. This decrease in spending does not bode well for colleges that offer applied engineering programs, because, in general, applied engineering programs depend on hands-on laboratories that prepare students for industrial employment. This is even harder for applied engineering programs at four-year teaching or comprehensive universities, because of the limited outside funding opportunities (Bayer & Sampat, 2016).

Many pre-fabricated trainer options from third-party vendors replicate industrial processes, but many times the trainers are expensive and utilize equipment not found in the industry, like banana plugs and pre-wired equipment. In addition to the downfalls of some trainers, they are often costly and hard to afford on an ever-shrinking college operating budget. This means that students lack specific skills because of reduced budgets. According to a mathematical model established over twenty years ago, the long-term effects of such budget cuts could lead to diminished economic development in repressed areas (de Pillis & de Pillis, 2001). In this paper, the author examines methods used at Murray State University to solve this problem.

Creating Trainers as Student Projects

The faculty and students of the Electromechanical Engineering Technology (EMT) program at Murray State University partnered with local industries to solve the problem of the effects of ever-increasing costs for trainers for the program's laboratories on a budget by utilizing donated equipment. The EMT program prepares students for positions as control or automation engineers in industry and focuses heavily on industrial automated systems. EMT faculty assign students in the program a project to design and build trainers for the college's automation and a controls laboratory with a specific budget and timeline. The students visit local industries to understand the industrial applications associated with the trainers, and are then divided into groups and to design the trainers and present their proposals to the class. The faculty choose the best design, and then the student groups work together to complete the trainers by the end of the semester, though sometimes the trainers are completed in stages within the limits of the approved budget. Often, industry will donate the more expensive needed equipment so that students can build the trainers at a fraction of the price. Students in subsequent courses have expressed satisfaction regarding working with these student-built laboratory trainers as part of their applied engineering curriculum, and the trainers become a recruiting tool to attract future students.

This method of designing and assembling laboratory trainers based on industry applications also helps applied engineering students develop soft skills that are sometimes hard to instruct. The projects teach students the importance of communication and management skills, while focusing on the applied design and fabrication of the trainers. It is also beneficial in creating and reading prints and following a budget. The EMT program requires an industrial instrumentation course, which needs a process trainer that utilizes the concepts of level, pressure, temperature, and flow control loops. The faculty received quotes for pre-fabricated industrial process trainers that met the needs of the laboratories. The prices for the trainers ranged from $34,000 to $78,000 per trainer. The program cost was too high, and the department could only spend $5000 at the time. The instructor assigned the class the seemingly impossible task of building three process trainers with the approved budget.

Literature Review

Universities and colleges utilize homemade trainers to give students the needed skills without purchasing expensive trainers. One example of this is the use of programmable logic controller (PLC) trainers. Chen, Tai, and Chen (2017) used a PLC and a human machine interface (HMI) to simulate “smart manufacturing devices” and then communicate with other devices via an Ethernet connection. An HMI generally consists of an interactive touch screen that allows operators to manipulate instructions within a PLC. The authors concluded that trainers do not require large sums of money. They felt, to the contrary, that the application of proper concepts can be allocated to fulfill Industry 4.0 concepts. Likewise, Sunomo and Asmara (2019) created homemade PLC laboratory trainers on a limited budget for vocational institutions. The authors did more than build a PLC trainer; they built a PLC with an ATMEGA processor and relay input and output cards. They also used a free software package called LDmicro to program the PLCs. Although Sunomo and Asmara’s trainers did not give students the same experience with the industrial software, they could replicate a similar experience on a lower budget. Creating trainers in classrooms creates a segue into flipping the course. A flipped classroom is a teaching approach that reverses the traditional model of classroom instruction.

In a flipped classroom, students are introduced to new material outside the classroom, usually through videos or readings, and class time is dedicated to applying that knowledge through discussion, activities, and problem-solving exercises. The idea behind the flipped classroom is that students can learn the basic concepts and principles at their own pace and in a way that suits their learning style. This approach allows teachers to spend more time creating trainers that give students real-world application skills. The flipped classroom proved to improve student learning and attention to courses during the COVID-19 pandemic, when many universities had to teach their content online (Tang, Abuhmaid, Olaimat, Oudat, Aldhaeebi & Bamanger, 2020). In addition to the advantages the flipped classrooms gave students during the pandemic, a study completed in 2017 found that students who took flipped engineering classes felt more effective than traditional engineering classes (Karabulut-Ilgu, Jaramillo Cherrez & Jahren, 2017). The authors compiled an extensive literature review of 62 articles that comprehensively reported positive outcomes from engineering courses that used the systematic approach and flipped their classrooms.

Having applied engineering students build their own trainers also decreases the cost of the university programs by saving the college thousands of dollars, when compared to buying third-party trainers. Building the trainers also allows colleges with lower budgets to add applied engineering programs in the United States and internationally. One example is a college in the Philippines that utilizes this method to teach automation engineering. The Low Cost 2 Station Industrial Automation Trainer is a highly effective and affordable tool for training students in industrial automation (Asuncion, 2019). The trainer offers two stations, each with its components, allowing students to work individually or in pairs to develop their skills. The trainer comes equipped with various sensors, actuators, and controllers, providing students hands-on experience with various automation technologies. The trainer is easy to set up and use, and the accompanying user manual provides clear instructions and guidance for students and instructors alike. Overall, the Low Cost 2 Station Industrial Automation Trainer is an excellent choice for institutions seeking an affordable and effective solution for training students in industrial automation. Lowering the cost of applied engineering programs is beneficial in many different ways.

Methodology

In this current project, the instructor set the budget and began by dividing the class into three groups. The class decided to replicate a water treatment plant, because the process exhibited each of the four needed processes. The instructor then used the water treatment plant as a system to teach each of the four main instrumentation concepts to the students. This systematic approach taught the students an essential industrial process, while teaching theoretical concepts associated with industrial instrumentation. The competencies that this trainer exemplified were theories associated with flow rates, pressures, level measurements, temperature measurements, and concepts associated with PLC programming.

Each group had a budget of \$1500, which left \$500 for unforeseen expenses. The instructor gave the groups four weeks to research and design the trainers. During this time, the students were encouraged to contact industry professionals in the instrument and controls (I&C) field and the local government water treatment workers. The research method taught students the importance of communication skills, and they learned that the operators were often as well versed in the operations of the equipment as the engineers. At the end of the four weeks, the students put their designs, parts lists, and lessons learned into a presentation to present to the entire class, a graded project in the course.

After the teams presented their ideas and concepts, there was a class meeting in which the instructor compiled all of the concepts presented in the previous class, and the class decided on a standardized design. The class ordered the parts and then designed and programmed the PLC programs, while waiting for delivery. Table 1 provides the list of parts used in construction of the trainers; however, the students did decide to purchase the Automation Direct Click PLC because of the small budget. It would have been hard to purchase a PLC brand used in industry to meet the application needs of the trainer with the given budget. The Click PLCs allowed the students to transfer their *RSLogix* (the Rockwell Automation software used for programming

Table 1. The list of parts used in construction of the trainers.

Qty.	Price	Name
1	$53.95	Sennotech Flow Master 1 GPM Water Flow Meter
1	$28.99	3 gallon Fish Tank kit for mixing
1	$39.99	5-gallon plastic reservoir tank
1	$14.99	Resistive level sensor
1	$69.99	NorthStar NSQ Series 12V Diaphragm Pump
2	$110.00	THMJ-C18-01 (Temperature Sensor)
3	$53.25	LFDPTG-3 3" Pressure & Temperature Gauge (0-50 psi)
1	$2.99	EASTMAN 1/4-in x 20-ft Pvc Clear Vinyl Tubing
2	$11.68	Screw In Style Water Heater Element, High-Watt Density
2	$84.72	LDI Industries - 1/2-20 Thread, 10-9/32 Inch Sight Length
1	$354.99	Automation Direct Click PLC with I/Os and Power Supply
1	$153.00	Automation Direct CMORE HMI Panel
1	$550.00	Festo Cart
	$50.00	Misc Wire, brackets, and screws
Total	$1,578.54	

their PLCs) knowledge to the free Automation Direct Click software. Students in the EMT program at Murray State University must complete EMT 310 – Programmable Logical Controllers before taking the EMT 312 – Instrumentation course. The instructor teaches the PLC class *RSLogix* programming software. Figure 1 shows the completed industrial instrumentation trainers built by the students in this project.

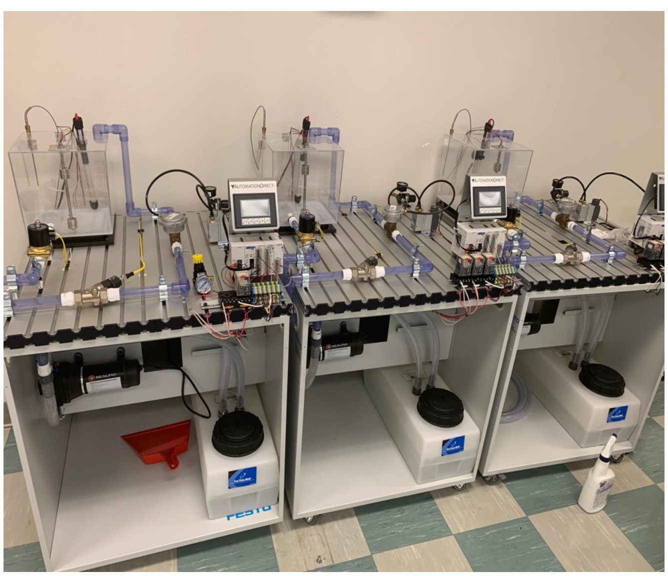

Figure 1. The complete industrial instrumentation trainers built by the students.

Table 1 lists the parts chosen for the process control trainer. The total price of the individual trainers was estimated at $1578.54 each. The estimate was over budget by $78.54, yet remained under the $5000 budget. The original budget was significantly higher than the budget in Figure 1, but students had to find alternatives to meet the outcomes of the trainers, while reducing the cost. One such decision was to utilize a fish tank instead of a more industrialized plastic tank. The fish tank kit included a light and an aerator that the students used to simulate the water treatment process. The instructor gave the students the rest of the class time to construct the trainers with their teams. One student acted as the engineering manager to ensure that construction of all the trainers was carried out as planned. The students downloaded the PLC and HMI programs to the trainers once they finished the fabrication. The fabrication project was a team project grade for the second grade of the project. The final grade was the teams' final presentation and demonstration to all of the faculty members of the college's program.

Survey Questions and Results

The students completed an end-of-project survey and answered the questions (included in Table 2) with a 1-4 Likert scale (1. I completely disagree; 2. I disagree; 3. I agree; and, 4. I completely agree). The overall survey results were positive, as the 12 students averaged a 3.4 out of 4 for enjoying the project. Interestingly, the students scored highest in the category indicating that they felt they learned more than other in classes. The literature review suggests that giving applied engineering students more hands-on projects increases their learning. The categories with the highest outcomes were that the students felt proud of their project, giving them more confidence when working on industrial-related projects. Overall, all the students' answers were above average, so the author considered the project successful.

Table 2. List of the questions that students were asked at the end of the project.

n=12	Results
1. I enjoyed the Process Control project for the course this semester.	3.44
2. I felt that the Process Control project was a good use of my time in the course.	3.33
3. I felt that I learned more from this class than from other Engineering Technology classes that did not embed similar projects.	3.11
4. I feel that the skills I learned while designing and fabricating the trainers will be helpful when I receive employment after college.	3.44
5. Similar projects should be embedded into the Engineering Technology coursework.	3.44
6. I feel proud that I was a part of the Process Control project.	3.67
7. This project gave me more confidence in working on industry-related projects.	3.56

Limitations

The limitations of the study are the low number of students surveyed. The project was a preliminary study, and future studies can build on this work. The limitations of future studies are that the projects are continually changing. The students might have a different experience with a more complex project than the process control project. There was also only one group of students to study, since this was the preliminary project. Another study should be performed with students who do not build trainers in order to create a benchmark, or control group, to compare the results of this study. Also, the Likert scale should be numbered one to five in future studies to allow students to remain neutral, with three being neutral.

Conclusions

One solution for reducing operating budgets for applied engineering programs in two- and four-year programs is to have students design and build laboratory trainers instead of purchasing expensive, pre-fabricated trainers. The students in this current project overwhelmingly felt pride in the project and felt that it would be a good idea to include similar projects in other applied engineering courses. The overall result of this project was that the school received three process control trainers for under $5000, and the students received real-world experience in designing and building the trainers. Another advantage for which it is harder to formulate results is the trainers' influence in recruiting new students that visit the labs. The much cheaper trainers performed with the same abilities as the more expensive third-party trainers. The author believes the trainers impact prospective students when they see the projects that former students built, because it demonstrates the hands-on projects in which students in the EMT program participate.

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Biography

JAKE HILDEBRANT is an associate professor at Murray State University and is the program coordinator for the Electromechanical Engineering Technology and Manufacturing Engineering Technology programs in their School of Engineering. He holds an AS in Electrical Engineering Technology, a BS in Electromechanical Engineering Technology from Murray State University, and an MS in Engineering Technology Management from Western Kentucky University. He also holds a Senior Controls Engineering certification from ATMAE. He is currently completing his PhD in Leadership from the University of the Cumberlands, where he is involved in research involving policies and procedures for engineering technology faculty. Mr. Hildebrant may be reached at jhildebrant@murraystate.edu

3D-Printed Tool Changer for

Maged Mikhail, Purdue University Northwest; Nelson Novales, Purdue University Northwest

Abstract

Additive manufacturing, also known as 3D printing, is exploding in the robotics industry. Not only does 3D printing enable more complex structures to be produced in additive manufacturing, it can also result in lower costs, greater versatility, and greater flexibility when creating customized tasks. End-of-arm tooling (EOAT) is a particularly important piece for the robot to be able to perform its duties. Appleton and Williams (1987) wrote that "a low-cost handling robot within a relatively inflexible machine tool system may contribute as little as 20% or an even smaller proportion of the total cost, whereas in an arc welding application the robot may be a 60% cost factor or higher." In this current study, the authors focused on the design and fabrication of a tool changer to prove the concept of a working robotic system to be able to perform an example of a real-world robotics application. Being able to quickly change a tool is an excellent feature for a robot to have, specifically EOAT that includes gripper jaws and suction cups. In this paper, the authors list the materials and designs, and demonstrate the tools used. Areas of improvement, programming application, and overall significance are also discussed.

Introduction

Tool changers increase the versatility of a robot and reduce the number of robot arms needed. This lessens the complexity of programs and allows for more tasks to be completed by one arm. The website Proto3000 states the following: "3D printing parts in FDM towards the production of EOATs provide dramatic time and cost savings while optimizing the performance of your entire workflow," and "with the growing use of robots in manufacturing, robotic grippers – essentially robot arms – are evolving to meet the needs of advanced applications in the automotive, electronics and food processing industries. This evolution has led to the development of lighter, customized robotic grippers with increased load capacity and safety features." (Application Spotlight, 2020). Not only does 3D printing allow for easy customization but also easy and affordable repair (UR robots, 2022; Mourtzis, Angelopoulos, Papadokostakis & Panopoulos, 2022).

The materials that are needed are the components of the Fanuc LR Mate 200id 4s, which are: power supply, controller teach pendant, manipulator, and hand-tool application. Materials that are not considered to be components of the Fanuc LR Mate 200id 4s are: gripper attachments, gripper posts, brass inserts, neodymium magnets, aluminum extrusion, and nuts and screws.

The grippers and the tool rack, shown later in this paper, were all printed on the Creality Ender 3 Pro with PLA filament. According to TWI-Global "PLA is a type of polyester made from fermented plant starch from corn, cassava, maize, sugarcane or sugar beet pulp" (TWI Global, 2023). These grippers were printed out of PLA, because of cost and accessibility. Printing with PLA requires no PPE, and the printer settings require only minor adjustments, depending on the brand. This filament behaves well and is easy and simple to use. Though this filament is not the strongest on the market, different infill patterns and thicknesses can be used to increase strength.

The STL files were sliced using Cura Ultimaker, which allows users to calculate cost and weight. A single set of the gripper base and all compatible attachments would have a material cost of around $1. The total print time is approximately 10 hours, which includes four hours of engineering time. The print time is calculated based on accuracy and quality settings set by the slicer software. These settings could be adjusted for a quicker print time, which could negatively affect print quality and overall strength of the gripper. Other material options would be nylon, which would be more heat resistant, or carbon fiber filament. These filaments are more abrasive and require different extruder nozzles, compared to the brass nozzles that come with the printer.

The concept for the tool changer is simple, as it uses a standard shape on the base that fits attachments for distinct functions if the finger attachment has the matching female end. Both the gripper base and finger attachment are fitted with a neodymium magnet that allows for the finger to snap into place. The gripper is designed in a way such that the magnets can be pressed into place without the need for glue or a fastener. Each neodymium magnet can hold up to 4 lbs. of force. This is increased by the amount of friction that is between the finger and the bass. These grippers are the most effective for lightweight operations. To increase the strength of the gripper, different magnet orientations could be experimented with. Figure 1 shows that, for ease of connection and disconnection, the magnet orientation was kept parallel with the finger attachment and base.

This design for the connection shape was an "X" shape to prevent the finger attachment from twisting as it gripped the object. Figure 2 shows that the ultimate intention for this design was that custom finger attachments could be printed for a wide range of applications to fit this profile. The two 2-inch-wide and suction-cup grippers were paired with posts that held the grippers after use. For customization purposes, the post had to be designed to properly hold the finger attachments after use. Both the two-inch and suction-cup grippers fit the same dimensions, allowing the same post to be used. Figure 3 shows that anything deviating from this design would require a different post shape.

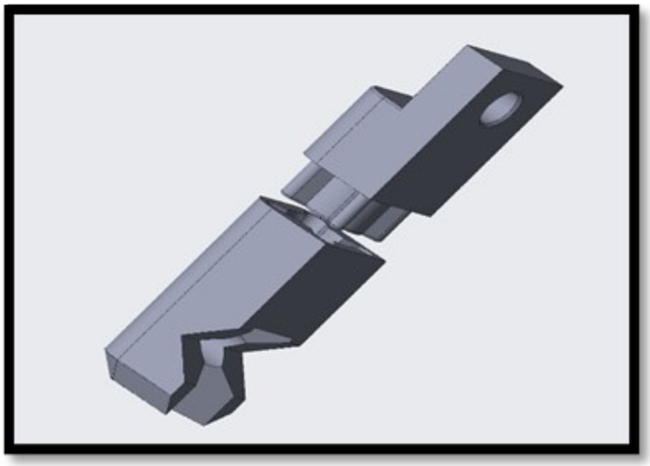

Figure 1. Gripper base and attachment assembly.

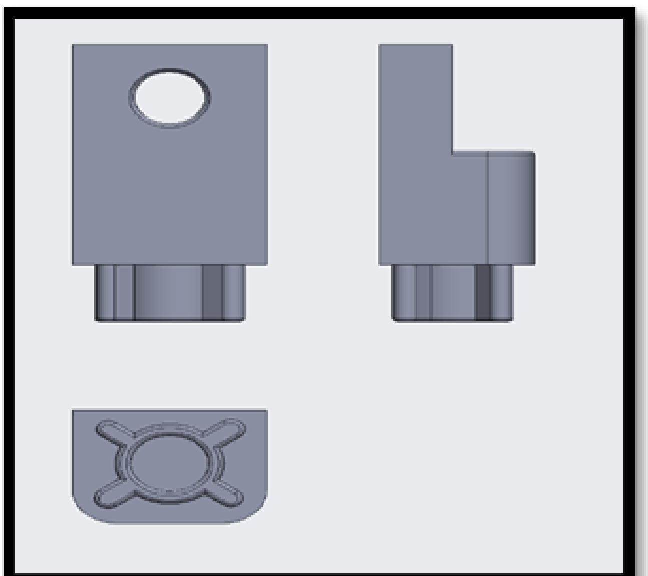

Figure 2. Gripper base displaying profile shapes.

Figure 4 shows how the two posts were mounted on aluminum extrusion. These materials were provided in the laboratory that was used for the course. The extrusions were screwed down to the corner of the table on which the robot was mounted. The grippers could essentially be mounted anywhere they would be most accessible to the robot. This design allowed the programmer to create a subprogram, or MACRO program, that could be used to change to a specific gripper. These subprograms or MACROs could be standard and used within a larger program.

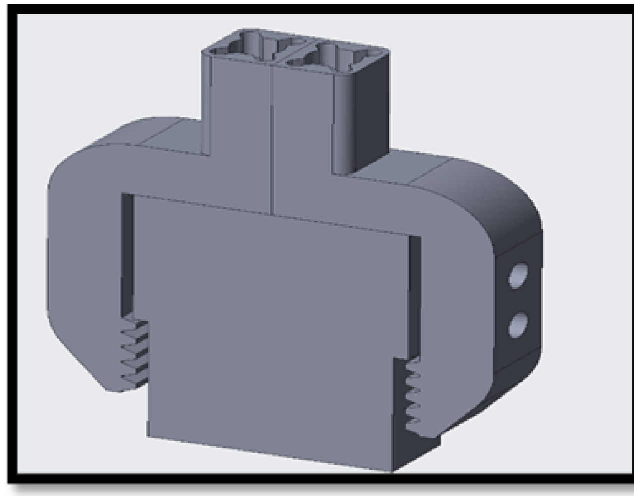

Figure 3. Two-inch-wide gripper and post assembly.

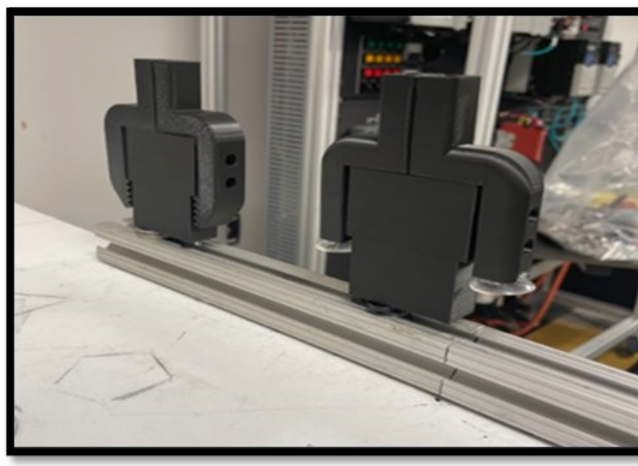

Figure 4. Aluminum extrusion with gripper posts.

Review of Literature

EOAT, or end-of-arm tooling, refers to the robotic tooling or gripper attached at the end of a robotic arm. EOAT is used in various industries to perform specific tasks, such as picking, placing, gripping, or manipulating objects. EOAT devices can be manufactured using traditional manufacturing techniques, such as machining, molding, or fabrication processes. Machining involves cutting, drilling, or shaping materials such as metals or plastics using milling machines, lathes, or other tools. Molding involves creating the desired shape by injecting molten material into a mold and allowing it to cool and solidify. Fabrication techniques involve cutting, bending, or welding materials to create the desired structure. The cost, time, and design of an EOAT device manufactured without 3D printers can vary depending on factors such as the complexity of the design, the materials used, the manufacturing processes involved, and the expertise of the manufacturer.

Machining and molding processes, for example, may require skilled labor and specialized equipment, which can increase the cost and time compared to 3D printing. Additionally, the design process may involve creating detailed engineering drawings and prototypes before final production, which can also add time and cost. 3D printers, also known as additive manufacturing machines, are devices that create three-dimensional objects by adding layers of material, typically plastic or metal, based on a digital design. They work by slicing a 3D model into thin cross-sectional layers and then depositing or solidifying the material layer by layer until the complete object is formed. This process allows for the creation of complex geometries and customized designs with relative ease.

The problem being solved by using a 3D-printed EOAT device in low-volume production is to save time and money. Traditional manufacturing methods such as machining or molding may require significant set-up time and tooling costs, and have limitations in producing complex shapes. By leveraging 3D-printing technology, an EOAT device can be rapidly prototyped, customized, and manufactured on-demand, reducing lead times and eliminating the need for expensive tooling. This approach can be particularly beneficial for low-volume production runs, where the cost and time associated with traditional manufacturing methods may not be justified.

Tool #1: Standard Gripper

This standard gripper can be used for simple shapes and operations, such as pick and place. The gripper opens as much as the gripper attachment allows. On the base of the gripper, there are brass inserts that allow for the gripper base to be fixed to the pneumatic gripper base. There is a hole in each side that allows it to be held in place by cap crews that are on the post. Figures 5 and 6 show the standard gripper attachment both in CAD and fabricated forms, respectively.

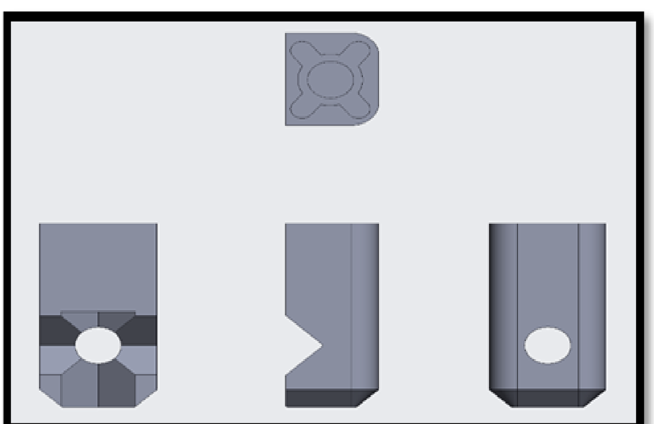

Figure 5. Standard gripper (CAD).

Figure 6. Standard gripper.

Figure 7 shows the fingers flexed outward, when evaluating the performance of the gripper. This could easily be solved by extending the length of the profile shape that fits into the finger attachment.

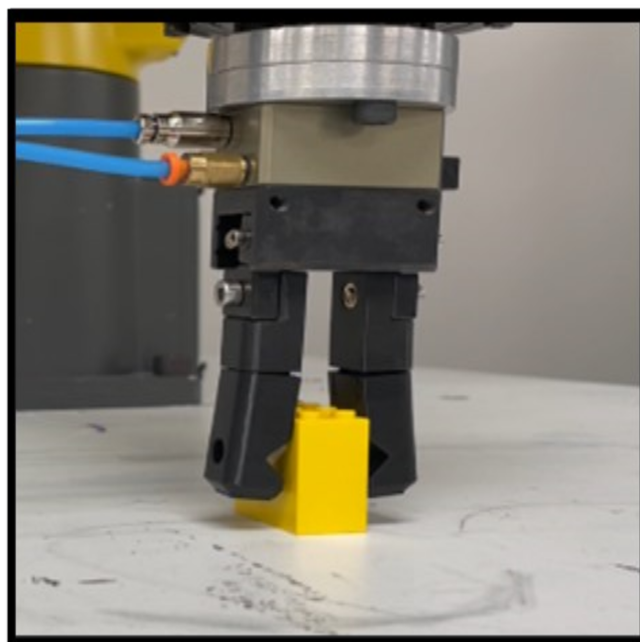

Figure 7. Standard gripper inward flex.

Tool #2: Two-inch-wide Gripper

This two-inch-wide gripper allows for larger objects to be picked up. This gripper was designed with a 2-inch diameter, 10 oz water bottle. As designed, the two-inch-wide gripper fit into the same profile as the standard gripper. Figures 8 and 9 show the CAD drawing and the fabricated tool docked at the post for Tool #2, respectively.

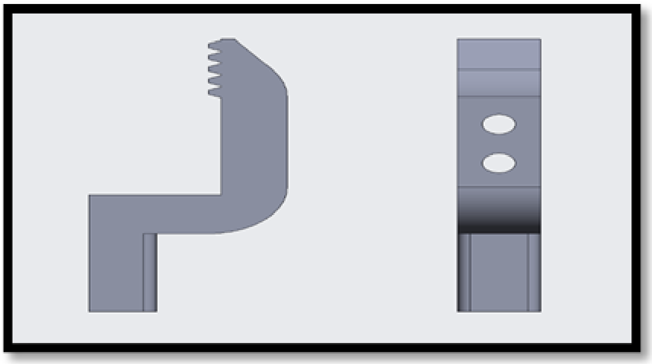

Figure 8. Two-inch-wide gripper (CAD).

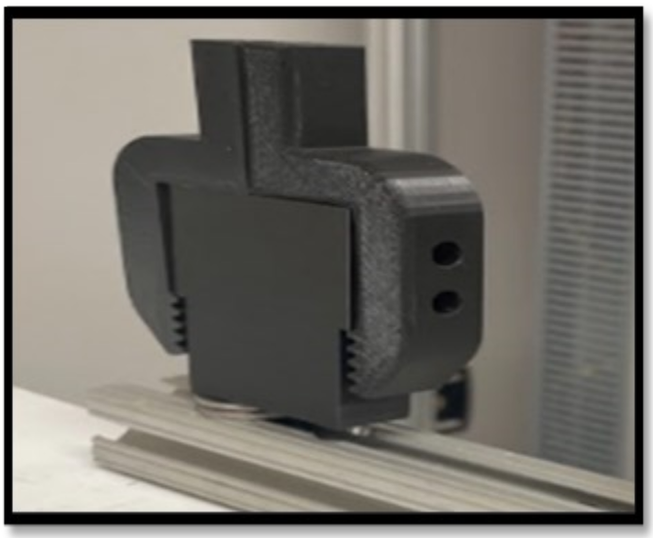

Figure 9. Two-inch-wide mounted gripper.

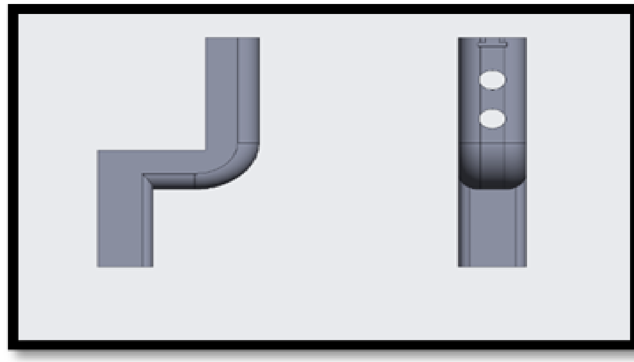

Figure 10. Suction-cup gripper (CAD).

Figure 11. Suction-cup mounted gripper.

Tool #3: Suction-Cup Gripper

This suction-cup gripper allowed for palletizing operations without the use of pneumatics. These suction cups released with the gripper being turned at an angle. It used suction cups to avoid using hoses, which would complicate the tool-changing process. Figure 10 shows how the gripper was designed with slots to allow for suction cups to be placed inside. The CAD drawing of Figure 10 shows a slot cut into the end of the finger attachment that fits a suction cup. Once inserted, the friction alone will hold the suction cup in place. Figure 11 shows how the suction cup, if preferred, can be secured with some hot glue. The decision in this project was made to use suction cups instead of a pneumatic vacuum gripper to allow for ease of change. This eliminated the difficulties of pneumatic hoses in the tool-changing process. This form of suction on an object would require that the object be placed in a fixed position when released, as the gripper would have to tilt for the suction cups to release the object. A dedicated pneumatic system must be used if the vacuum suction is preferred.

Tool-Changing Process

The process to change tools is simple, given the design and the vertical orientation of the magnets, as noted earlier. This process functions in one direction to select a new tool and can be reversed to return a tool to its post. Figures 12-15 show how this process can be applied to both the two-inch gripper and the suction-cup gripper. The gripper base, once all of the gripper attachments have been removed, must be in the closed position. Once there is proper alignment, the robot arm can be lowered into position. Once the magnets make contact, the gripper can be opened and raised, allowing the gripper attachment to be used. Figure 13 shows that, when lowering the gripper base into the finger attachment, the speed should be brought down. The slower motion will allow for a more exact alignment of the magnets. Once the gripper is open to release the post, the retract motion may be rapid. This also applies to the robot positioning itself above the finger attachments.

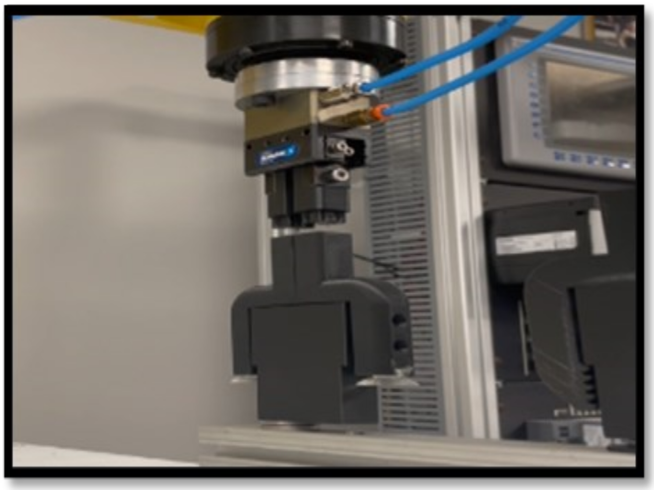

Figure 12. Gripper base alignment.

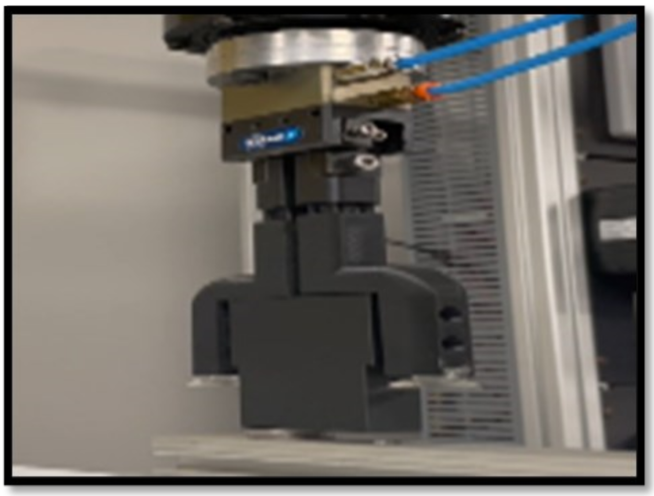

Figure 13. Gripper base lowered into position.

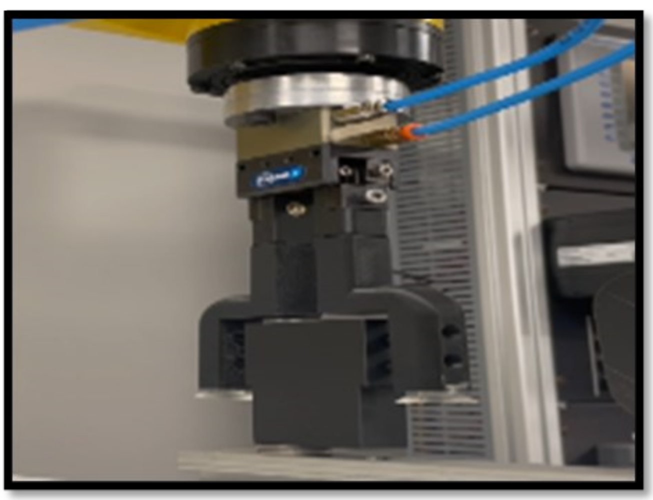

Figure 14. Gripper opened.

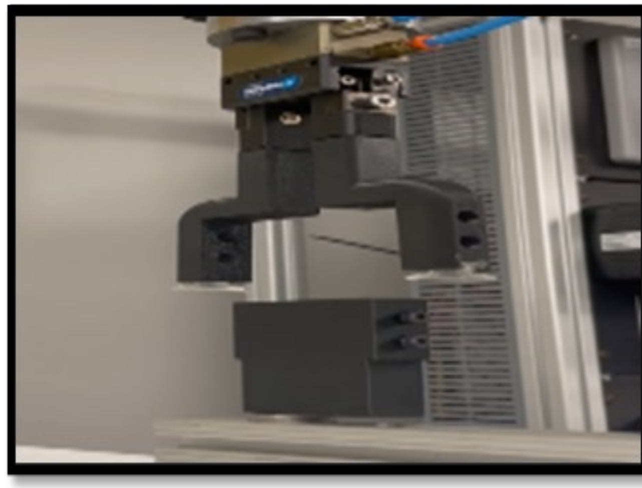

Figure 15. Gripper raised.

Applications

In this current project, each gripper was designed for a specific task. Due to easy customization with 3D printing, each gripper was designed with a specific task in mind. The standard gripper, however, was designed to function for various simple tasks, such as the one shown in Figure 7. Figure 16 shows that the two-inch-wide gripper was designed to pick up an empty 10 oz. water bottle.

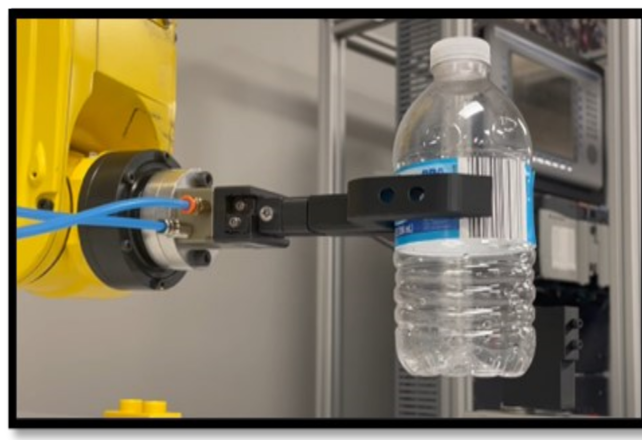

Figure 16. Two-inch gripper holding a 10 oz. water bottle.

The reach and range of motion of the robot must be considered, when deciding on a location for the tool rack. While performing tests on the grippers, location of the tool rack was observed by operators. The suction-cup gripper, when applied, has a limited list of objects it can hold. Aside from the weight limit, the suction cups work best with smooth surfaces. The application for this gripper was to lift a smartphone. Figure 17 shows that the screen of the phone served as a perfect surface for the suction cups to hold onto.

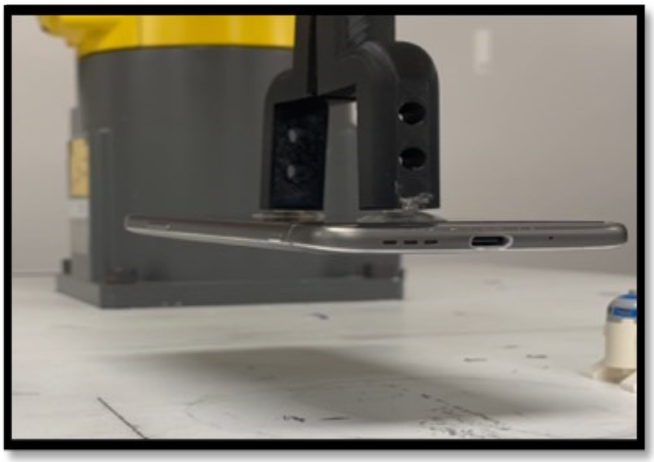

Figure 17. Suction-cup gripper holding a smart phone.

As mentioned earlier, the lack of vacuum suction required that the suction cups release the object by having it fixed, while the gripper tilted at an angle. This would be good for shelving or racking objects that are held in place by the shelf or rack itself. But when using this gripper, the operator must ensure good contact between the suction cup and the surface of the object.

Conclusions

This project demonstrated the ease with which a tool-change system can be developed. Any gripper design that fits the same profile shape can be used with this changeable gripper base (End of Arm Tooling 3D Printing, 2019). With a variety of 3D printer filaments and infill patterns, the strength and durability of the grippers can be increased. This can expand the range of how one robot arm is used and reduce the overall cost of a robotic arm. 3D printing essentially reduces production time. It is also combined with the ease of low-volume production found in fast prototyping. As a result, when it comes to creating tool parts and grippers, the possibilities are endless (Hay, 2021).

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Biography

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Industry 4.0 Integration into a Manufacturing Engineering Graduate Certificate and MS Degree

David Labyak, Michigan Technological University; John L. Irwin, Michigan Technological University

Abstract

Industry 4.0 topics were integrated into a newly established graduate certificate in Manufacturing Engineering (CME) and Master of Science in Manufacturing Engineering (MSME) degree. The SME Four Pillars of Manufacturing Engineering inspired the curriculum design. The online courses offered are suited for industry professionals and graduates from electrical or computer engineering, materials science and engineering, manufacturing/mechanical engineering and engineering technology degree programs. The MSME has 16 required credits, including statistics, safety, leadership, tolerance analysis, communications, and industry 4.0. The remaining 14 credits are elected from emphasis areas in additive manufacturing, manufacturing systems and operations, product tooling and assembly engineering, quality engineering, manufacturing sustainability, advanced materials and manufacturing processes, cyber physical systems, or others to be determined by the graduate degree advisor. In this paper, the authors present the design, development, and assessment of the Industry 4.0 Concepts course. Course assignment and student course evaluation data were used to assess the degree to which the course met the learning outcomes.

Industry 4.0 Concepts is a three-credit course that explores topics such as smart factories, cyber physical systems, proactive maintenance, computer simulation, horizontal and vertical integration, and barriers to implementation. The course was designed so that students could accomplish four main learning outcomes. These illustrated the interconnection of machines, devices, sensors, and people to the Internet of Things (IoT) and Internet of People (IoP) to form the Internet of Everything (IoE). Additional concepts included in the course were the ability to demonstrate how information transparency is accomplished through tasks, from the virtual and physical worlds; to propose decentralized decisions based on the interconnection of objects and people, along with information transparency; and, to assess the shifting role of humans operating machines towards a strategic decision-maker and problem-solver role.

Introduction: Industry 4.0 Trends

Figure 1 shows how Industry 4.0 was integrated into the components of advanced manufacturing—such as smart manufacturing, modeling, simulation, additive manufacturing, and advanced materials. The fourth industrial revolution, coined as Industry 4.0, is a popular advanced manufacturing topic with numerous workshops, conferences, and seminars offered worldwide. Industry 4.0 STEM education research calls for a revision of manufacturing-related curricula (Alasti, 2021; Das, Kleinke & Pistrui, 2021). The advanced manufacturing landscape is changing exponentially, and manufacturing education is striving to keep up with these rapid changes. Industry 4.0 is the key to future success in advanced manufacturing (Kota & Mahoney, 2018; House, 2018; Huderson, Peiffer, Shamsi, Plaza & Collins, 2022).

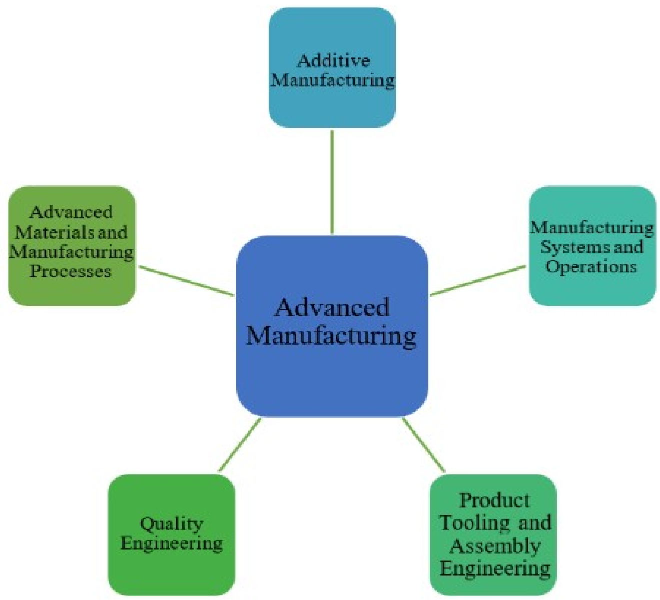

Figure 1. Advanced manufacturing components.

The Four Pillars of Manufacturing Knowledge (SME, 2011) that is used to guide manufacturing curricula also includes Industry 4.0 topics. The Four Pillars are aligned with the ABET Accreditation standards for Manufacturing Engineering (ABET, Inc., 2022), and SME Body of Knowledge (SME, 2020), which has a new focus area that was added for Digital Enterprise. This area focuses on the increasing impact that digital technologies have on manufacturing, featuring expanded coverage of topics such as the Industrial Internet of Things (IIoT), data science, digital performance management, artificial and augmented intelligence, machine health/asset optimization, digital twins, and digital threads. Figure 2 shows a graphic representation of the Four Pillars as a structure, including foundation and the supporting pillars. Industry 4.0 topics that have been integrated into the MSME curriculum are Tolerance Analysis/GD&T (Product Design knowledge block), Rapid Prototyping (Process Design knowledge block), and the topics in the Automated Systems and Controls knowledge block are related to Industry 4.0.

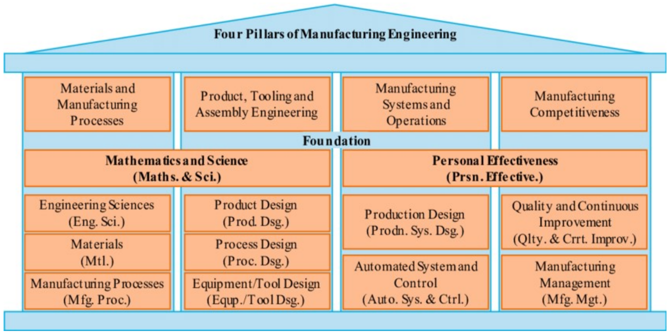

Figure 2. SME Four Pillars. Reprinted with permission.

Development of the Four Pillars was initiated by the Society of Manufacturing Engineers (SME) through its Center for Education (SME, 2012). Lead author, Robert L. Mott, is Professor Emeritus of engineering technology at the University of Dayton, and at that time was a member of the Steering Committee of the SME Manufacturing Education & Research Community (SME-MERC), and Senior Staff of the NSF-sponsored National Center for Manufacturing Education located at UD. Later, several manufacturing education researchers used the SME Four Pillars as a curriculum-development model for manufacturing engineering and manufacturing engineering technology degree programs (Mott, Stratton, Jack, Gartenlaub, Bennett, Wendel.... & Raju, 2012; Nutter, Mott, Williams & Stratton, 2013; Nutter & Jack, 2013; Mott & Jack, 2013; Mott, Bennett, Gartenlaub, Danielson, Stratton, Jack, H.... & Waldrop, 2013; Yip-Hoi & Newcomer, 2015).

The SME Four Pillars is currently in the process of being reviewed and updated by advanced manufacturing experts to include modern Industry 4.0 topics (Irwin, Johnson & Marzano, 2022). In 2021, SME administered an online survey to approximately 350 subjects, 75 of whom were returned, yielding a response rate of approximately 21%. Figure 3 shows that the Automated Systems and Control knowledge block was deemed most relevant to Industry 4.0 topics.

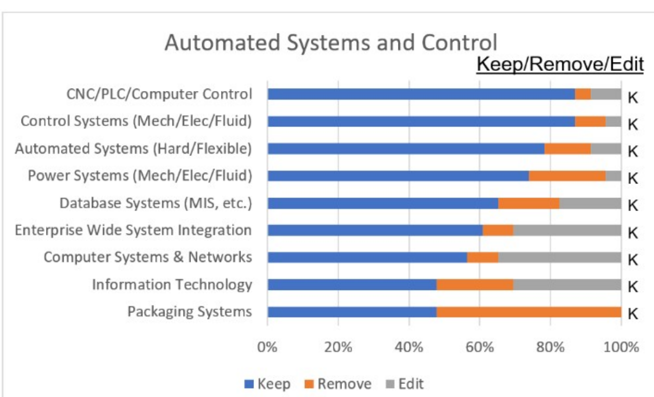

Figure 3. Survey results: automated systems and control knowledge block.

The topic with the most suggested edits was Computer Systems & Networks. Here are the suggestions that were provided:

- Real-time Analytics & Optimization
- Include closed-loop adaptive, artificial intelligence, integrate deep physics with manufacturing
- Incorporate Smart Factory + Operations Technology & Information Technology
- Computing and communication architectures and technologies
- Computer Systems, Networks, and Cyber-Security
- Real-Time Machine Control and Machine Management

The survey also requested suggestions for additional topics for the Automated Systems & Control knowledge block. The topics suggested were:

- Smart System Integration
- Include Edge and Cloud integration
- Factory & Supply Chain Optimization
- Enterprise-Wide Systems and technologies (Advanced systems control and coordination, Plant-floor information systems, Cybersecurity)

Context of the Study

The CME and MSME are offered in the Department of Manufacturing and Mechanical Engineering Technology (MMET). The nine-credit online CME was introduced in the 2021 fall semester. The CME has two required courses (six credits) that are also required in the MSME. These courses prepare students to manage and/or provide leadership for teams to successfully implement manufacturing processes, and to communicate effectively utilizing the fundamental concepts of geometric dimensioning and tolerance analysis. Industry 4.0 Concepts is an elective course in the CME. The 30-credit MSME was introduced in the 2022 fall semester. Nine of the required 16 credits are also required in the CME. The 16 credits of required courses for the MSME are:

- Statistical Methods (3)
- Key Factors of Holistic Safety (1)
- *Organizational Leadership (3)
- *Tolerance Analysis with Geometric Dimensioning & Tolerancing (3)
- *Industry 4.0 Concepts (3)
- Professional Engineering Communication (3) Or Engineering Research Communication (3)

(*Also CME courses)

Industry 4.0-related topics are integrated into the remaining 14 credits of courses chosen from emphasis areas such as: additive manufacturing, manufacturing systems and operations, product tooling and assembly engineering, quality engineering, manufacturing sustainability, advanced materials and manufacturing processes, and cyber physical systems.

Industry 4.0 Concepts: Course Design and Delivery

The Industry 4.0 Concepts course enrollment in the spring semester of 2022 was nine students. A Canvas learning management system section was created for the enrolled students. All students enrolled were off campus in remote settings. The Canvas section was developed to allow students to access the course content at their convenience. The following methodology was used for the online setting:

- Recorded lectures to present course topics and content
- Reading assignments from available literature
- Discussion assignments on course topics and literature reviews
- Homework assignments
- Course quizzes and final exam

For the majority of the course, recorded lectures were used to present course topics and introduce the content covered. Presentation slides were used in conjunction with the recorded lectures. Reading assignments, from available research, were given to the students to review and then participate in a series of discussion postings. The discussions were used to make sure the students were completing the reading assignments, and to allow them to interact with each other. Two homework assignments were collected during the course that covered machine learning using MATLAB.

This software has built-in functions that are specifically tailored for machine learning applications. The assignments were focused on how to use these functions. Four periodic quizzes were given during the semester, along with a final exam at the conclusion of the course. The quizzes were used to determine the students' understanding of content covered in recorded lectures, and to make sure they were reviewing the posted material. This provided an alternative to just using online discussion boards. The final exam at the conclusion of the course provided an overall assessment for each student.

Industry 4.0 Concepts: Course Content

In this course, students examine Industry 4.0 as it relates to manufacturing. The fourth industrial revolution has begun with the introduction of machine intelligence and cyber physical systems that can communicate over the internet. Cyber physical systems enable the virtual world of computers and software to merge with the physical world through process management and feedback. This is a result of hardware being much more affordable, readily available software that can perform complex tasks, inexpensive computational storage, and a widespread internet, all of which connects machines, devices, sensors, data, and people.

Course Learning Outcomes:

1) Illustrate how the interconnection of machines, devices, sensors, and people connect the Internet of Things (IoT) and Internet of People (IoP) to form the Internet of Everything (IoE).
2) Demonstrate how Information Transparency is accomplished through tasks from the virtual and physical world.
3) Propose Decentralized Decisions based on the interconnection of objects and people, along with Information Transparency.
4) Assess the shifting role of humans operating machines towards a strategic decisionmaker and problem-solver role.

As it relates to manufacturing, students explore topics such as smart factories, cyber physical systems, proactive maintenance, computer simulation, horizontal and vertical integration, and barriers to implementation will be explored. As an example, connected sensors will integrate an Internet of Things (IoT) network on the factory floor collecting data that will be stored in the cloud and be processed with cloud computing. The large amount of collected data (i.e., Big Data) will enable the use of computing methods including artificial intelligence to study system energy efficiency, tool wear, preventive maintenance, and product quality management. The connected factory floor, in conjunction with the use of smart human machine interfaces (HMIs), also enables the use of real-time data in automation, system integration, and supervisory control to minimize down-time. Furthermore, the collected data will enable the development of process emulators to simulate the steps of a process before actual production begins in order to increase efficiency through intelligent routing.

Student Demographics

Of the students, eight graduate students were taking the course towards fulfilling their degree requirements, and one undergraduate student was taking the course for continuing education. All of the students were working full time during the course and four were employed as part of a co-op or internship program.

Results: Teaching Evaluations and Student Comments

At the end of the course, a course evaluation was given to the students enrolled in the online class. The overall response rate was 7/9, or 77.78%. There were 15 evaluation questions ranging from how the students understood the goals and objectives of the class, were the students' efforts in the course adequate to meet the course objectives, how well the instructor communicated the material, how well the instructor engaged student participation, did the instructor provide timely feedback on homework/assignments, and if the instructor created an atmosphere in which ideas could be

Table 1. Student demographics during course offering.

Student Demographics (9 Students)		
Type of Student		
Graduate	8	Taking the course as part of degree requirement
Undergraduate	1	Taking the course for Continued Education
Student Major		
MS Manufacturing Engineering	5	Currently enrolled at MTU
MS Mechatronics	2	Currently enrolled at MTU
MS Mechanical Engineering	1	Currently enrolled at MTU
BS Mechanical Engineering	1	Past Graduate of MTU
Student Employment Status		
Full Time	5	Employed full time during course
Co-op/Intern	4	Employed as a Co-op/Intern during course
Full Time Student	0	Not employed during course

Table 2. Student evaluations: seven-dimension scoring.

Student Evaluations - Seven Dimensions		
	Question	**Response Average**
1	The instructor was enthusiastic about the subject matter of the course	4.29
2	The instructor communicated the course material clearly	4.43
3	The instructor engaged students by encouraging participation during class	3.86
4	The instructor engaged students by encouraging course preparation, reflection or other activities outside of class	3.71
5	The instructor provided timely feedback on my work (homework, assignments, exams, etc.)	3.86
6	The instructor displayed a personal interest in students and their learning	4.14
7	The instructor used technology appropriately	4.00

exchanged freely and easily. Questions were weighted from 1 (strongly disagree) to 5 (strongly agree). The evaluation mean of the Seven Dimensions for the course was 4.04. The highest evaluation average was for how well the instructor communicated the course material. The lowest evaluation average was 3.71 for how well the instructor engaged students by encouraging course preparation, reflection or other activities outside of class.

Student comments for the course were limited, but did provide some helpful guidance in course improvement. One question in the evaluation was "What aspects of this course should I change to improve student learning?" One comment suggested consistent scheduling for assignments of reading/videos and more graded assignments such as every Sunday night or Monday morning. This was geared towards the student that was working full time as opposed to a traditional on-campus student. Another comment was a student wanting to see Zoom or other group gathering sessions, where they could have a class discussion for each topic to exchange ideas rather than typing comments in a reply or reflection posting. They felt more information could be exchanged through a group setting as compared to typing a response. Another question was, "As I, the instructor, prepare to teach this class again, what aspects of this course (teaching methods, assignments, areas of emphasis, etc.) should I preserve that effectively furthered your learning?" Responses from this question were positive in that they liked the class, it was not repetitive, and there was no redundant busy work. Another student liked the use of multiple sources of videos and various research papers.

Discussion

The course evaluation and student comments will help in course improvement, although all comments were related to course delivery rather than course content. Since this course was offered online during the spring semester, the next time the course is offered these suggestions will be taken seriously to adjust the course to better align with non-traditional students. Having regularly scheduled group Zoom meetings was a great idea for one. This can provide an environment for students to learn from each other as opposed to typing a response that they think best fits what the instructor wants to hear. Timing for these online meetings is always a challenge; however, if an event schedule is posted early in the semester, it aids working professionals in time management. Additionally, having a regular and consistent schedule for non-traditional students helps them keep on track without having to consistently check the course schedule. They will know up front what to do when, so they can plan their week accordingly.

Conclusions

All students achieved all course learning outcomes at acceptable levels. The course received high student evaluation ratings with no comments pertaining to course content. Therefore, the course content seems to be enough to meet the learning outcomes. Since the topic of Industry 4.0 is an evolving topic, continuous updating of course material will be required. For instance, refreshing the list of research papers used for literature reviews. The Industry 4.0 course is currently being offered as an asynchronous online format only, but will have an on-demand, in-person component in the future. To prepare for the online format, efforts are underway by the university's Center for Teaching and Learning to coordinate all the online courses with a standard format using Canvas. This will allow faculty and students to reach the goals according to the Quality Matters Program (2015) rubrics and standards to ensure that learners are engaging with high-quality courses.

To help integrate Industry 4.0 topics in future course offerings, course evaluations and student comments provide a helpful insight for what the students liked and disliked about the course. Since this course was mainly taken by working professionals, a consistent course and traditional face-to-face interaction was indicated as being important, even though it is offered as an online class. These suggestions will help steer the future course structure in order to provide improved learning outcomes.

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