Experiential Learning vs Traditional Classroom Lecture for Lean Manufacturing Education

by

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Abstract

This study involved Lean Manufacturing (LM) education conducted within a Simulated Factory (SF). Experiential Learning Theory was used to design the training. The purpose of this study was to validate the efficacy of the Experiential Learning (EL) method, with a focus on the Lean Manufacturing (LM) sub-topic of Just-In-Time (JIT). While there are many examples of Experiential Learning (EL) for Lean Manufacturing (LM) education in a Simulated Factory (SF) cited in this study, efficacy validation has relied primarily on qualitative data. Building a Simulated Factory (SF) requires significant investment; therefore, quantitative research to demonstrate the superior efficacy of this approach will be helpful to Lean Manufacturing (LM) educators in justifying investment.

Lean Manufacturing (LM) is the 3rd generation of Manufacturing after the Job Shop and Henry Ford's Mass Production System (Black & Phillips, 2013). Lean was coined in the landmark book; "*The Machine That Changed the World*" to describe the Toyota Production System (Womack et al., 1990, p. 13). The "Father of the Toyota Production System" was Taiichi Ohno, Toyota's Executive Vice President from 1975 to 1978. Ohno spent many years perfecting the Lean system from shop floor supervisor to executive vice president.

Lean Manufacturing (LM) is challenging to teach in a traditional classroom environment, which has led to many Simulated Factories (SF) being set up in universities. Manufacturing companies train their employees within their operations. Hands-on experience in a realistic shop floor environment is the most suitable way to internalize lean concepts (Abele et al., 2010).

The Lean Manufacturing (LM) sub-topic of Just-In-Time (JIT) is particularly difficult to comprehend in a lecture environment. Taiichi Ohno sent senior managers to supplier locations to

teach and implement (JIT) methods. Past teaching attempts failed, and Ohno concluded that Just-In-Time (JIT) must be taught while being implemented at supplier locations.

Jim Womack, the author of “*The Machine That Changed the World* and “*Lean Thinking*,” stated in the forward of the book “*Learning to See*” by Rother and Shook that step 4 of the step-by-step lean transformation process described in Chapter 11 of *Lean Thinking* is the most important step in a company's lean transformation journey and the step most often skipped in the 5-step process. Step 4 involves mapping the entire value stream for all product families. “*Learning to See*” is a seminal Lean Manufacturing book explaining the Value Stream Mapping Process (Rother et al., 2003).

Value Stream Mapping (VSM) is a Just-In-Time (JIT) tool used to uncover waste within a manufacturing system. Trainees understand the importance of Value Stream Mapping (VSM) on an intellectual level; however, implementation requires experience for the deep understanding needed for use. This study followed Kolb's experiential learning cycle (Kolb, 1984) to design Just-In-Time (JIT) training within a Simulated Factory (SF) to improve the efficacy of Just-In-Time (JIT) instruction.

Four tests were conducted to compare Pre- and Post-test survey results for students with Classroom Lectures and Experiential Learning in a Simulated Factor (CLELSF) vs. students with Classroom Lectures (CL) only. The data indicated improved efficacy for those students engaged in experiential learning within the lab. Distance students without the benefit of the lab experience performed at the same level, likely due to their Adult Learner status.

Of the four sub-topic areas of Lean Manufacturing tested, Just-In-Time (JIT) knowledge improved at a greater rate when compared to Jidoka, and Standardization and overall Lean Manufacturing knowledge.

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CHAPTER 1. INTRODUCTION

Background

This chapter introduces the following topics that inform the study:

- Adult Education with emphasis on Experiential Learning Theory
- Lean Manufacturing (LM) and the supporting sub-topic areas of Lean and the Simulated Factory (SF) environment that house the design methods of the study.
- The interdependence of Lean Manufacturing (LM) sub-topic areas is described to show how each sub-topic area of Lean Manufacturing (LM) is related.

Purpose of Study

A validated Experiential Learning (EL) approach in teaching Lean Manufacturing (LM) principles improves student knowledge. It ensures that students going to industry understand and can apply the Lean Manufacturing (LM) tools required to eliminate waste and redesign operating systems. Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165). This study also supports educators in making a case for Simulated Factories (SF) to funding agencies.

When teaching Lean Manufacturing (LM), the importance of the Just-In-Time (JIT) sub-topic is clear, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation, Rother et al, 2003). The hesitancy of managers to utilize this most important tool is an integral part of this study leading to the formulation of one of the three research questions, which focused on Just-In-Time (JIT) knowledge with 16 questions of a 47-question survey related to Just-In-Time (JIT). These 16 questions were administered to independent sample groups: students engaged in classroom lectures and experiential learning in the Simulated Factory (CLELSF) and students with classroom lectures (CL) only.

The 47 questions survey represents four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10) and JIT (16). The questions are used to test for differences between On-Campus and Distance students. It was expected that students engaged in (CLELSF) would show improvement in all sub-topic areas of Lean Manufacturing (LM) with more significant improvement in Just-In-Time (JIT) knowledge over students with (CL).

Research Questions

The following research questions were posed in the study:

RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

RQ3: Is there a performance difference between "On-Campus" students and "Distance" students?

Distance students represented the (CL) or "No Lab" independent sample in this study, while "On-Campus" students represented (CLELSF) or students with "Lab." There may be a difference between these two groups beyond instruction. In one limited data set, On-Campus students represent the Independent Sample (CL) or "No Lab" due to the COVID isolation period in which lab activities were canceled. This data set measures the JIT sub-topic questions only.

Overview

Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success. With recent advances and intense competition in manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165).

Lean Manufacturing (LM) is more than just a set of tools. A Lean Manufacturing (LM) culture is required to activate the system. Two of the 14 principles identified in the influential book "*The Toyota Way*" are Principle 10: Develop exceptional people and teams who follow your company's philosophy. Principle 14: Become a learning organization through relentless reflection and continuous improvement. (Liker, 2004, p. 250). The emphasis on people and teams is critical to the historical success of the Lean Manufacturing (LM) discipline. The approach to learning and developing people to support the continuous improvement of organizations is consistent with Experiential Learning Theory (ELT). John Dewey emphasizes the importance of experienced-based learning in the following passage:

> Discipline is genuinely educative only as it represents a reaction of information, if not the individual's own powers, so that he brings them under control for social ends. Culture, if

it is to be genuinely educative and not an external polish or factitious varnish, represents the vital union of information and discipline. The attempt to attach genuine moral effectiveness to a mere process of learning, and to the habits which go along with learning, can result only in a training infected with formality, arbitrariness, and an undue emphasis upon failure to conform. (Dewey, 1909, p. 20)

Adult Education and Experiential Learning

Adult Education can refer to the planned educational activities that assist adult learners with improving their knowledge, skills, and abilities (Galbraith, 2004). What constitutes an adult will vary due to the individual's social, maturation, cultural, biological, and psychological differences; however, Adult Education primarily refers to individuals involved in post-secondary learning activities, such as the students in this study. The link between adult education and the surrounding environment is an important one. The link is important because of the continual changes taking place throughout the workplace, home and community. Understanding how to address adult learners' needs is vital and can be accomplished through the use of experiential learning techniques and strategies.

Many have attempted to define Adult Education with little success. "Extracting adult education from its surrounding social milieu is as difficult as determining how many angels can dance on the head of a pin" (McCullough, 1980, p. 158). The effort to describe what counts as adult education is tied up with the desire to establish a separate identity from other education. While these issues are still very much present, some common ground has emerged (Merriam & Brockett, 2011).

"Adult education is a practice in which adults engage in systematic and sustained learning activities in order to gain new forms of knowledge, skills, attitudes, or values. It can

> encompass everything from basic literacy to personal fulfillment as a lifelong learner, and to ensure the fulfillment of an individual's career goals. The purpose of adult education can be to enhance personal development, improve professional skills, and foster community development and social inclusion" (Merriam & Brockett, 2007, p. 9).

Brookfield (2013, p. 5) defines adult education as follows:

> "Adult education is a broad term that encompasses a range of activities that aim to provide adults with the knowledge, skills, and values needed for their personal development, employment, and participation in society. It includes basic literacy and numeracy training, vocational education, continuing professional development, and community education,"

This study focused on applying Experiential Learning Theory (ELT) to Lean Manufacturing (LM) education. Kolb (1984) stated, "Experiential Learning Theory (ELT) is fundamentally different from behavioral and cognitive learning theories" (p. 20). Kolb further explained that the term experiential is used for two reasons: it is tied to the work of Piaget, Dewey, and Lewin and the central role experience plays in the learning process.

> "This differentiates Experiential Learning Theory (ELT) from rationalists and other cognitive theories of learning that tend to give primary emphasis to the acquisition, manipulation, and recall of abstract symbols and from behavioral learning theories that deny any role for consciousness and subjective experience in the learning process" (Kolb, 1984, p. 20).

John Dewey cited a true example of a school that teaches swimming without a pool. A participant was asked what happened when he got into the water, to which he stated, "I sank."

Judgment, as the sense of relative values, involves the ability to select and discriminate. Acquiring information can never develop the power of Judgment. The development of Judgment is despite, not because of, methods of instruction that emphasize simple learning. The test comes only when the information acquired has to be put to use. (Dewey & Hinchey, 2019, p. 31)

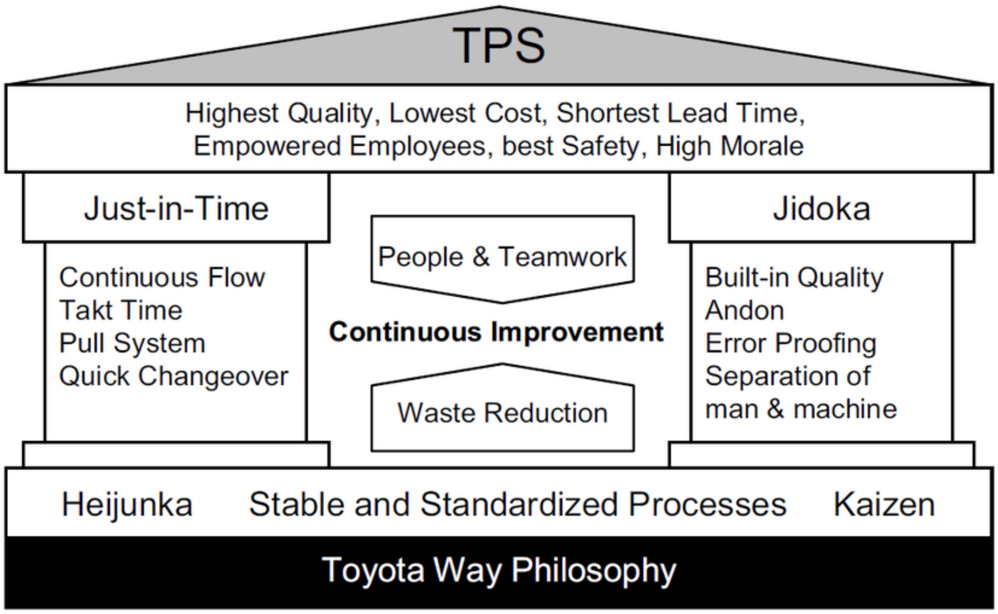
The choice of Just-In-Time (JIT) as a focus area for one of the research questions is due to the difficulty students have in understanding the conceptual philosophy of Just-In-Time (JIT). The Lean House (see Figure 1) summarizes the discipline of Lean Manufacturing (LM). Just-In-Time (JIT) represents one of the two pillars of the Lean House.

Just-In-Time (JIT) is challenging to teach in a traditional classroom environment. Taiichi Ohno, considered "The Father of the Toyota Production System," sent senior managers, not up for promotion, to supplier locations to teach Just-In-Time (JIT). Past teaching attempts had failed, and Ohno concluded that teaching must coincide with implementation at the supplier location (Ohno, 1988). Jim Womack, the author of *Lean Thinking*, indicated that Value Stream Mapping (VSM), a tool of Just-In-Time (JIT), is the most important step employed for lean transformation, and the step most often skipped in the 10-step process (Rother et al., 2003).

Value Stream Mapping (VSM) is often ignored, likely because it is difficult to understand and apply. Thus, it undermines successful lean transformation (Rother et al., 2003).

Figure 1

The Lean House



Source*:* Romvall, K. & Wiktorsson, M. & Bellgran, M. (2010).

Lean Manufacturing

Lean Manufacturing (LM) represents the third generation of Manufacturing after the Job Shop and Henry Ford's Mass Production System (Black & Phillips, 2013). Lean Manufacturing (LM) was the term coined in The Machine That Changed the World (Womack et al., 1990) to describe the Toyota Production System (TPS). Lean Manufacturing (LM) is an operating system that drives waste elimination continuously. Toyota identified three categories of waste: Muri (overburden), Mura (unevenness of production schedules), and Muda, which represents seven wastes inherent in all manufacturing systems identified as Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, and Defects (Liker, 2004, pp. 27–30).

The growth and availability of Lean Manufacturing (LM) training is surprising, given the term “Lean” was not defined until 1990. University certifications are ubiquitous. Top-ranked institutions, such as Harvard, Purdue, Georgia Tech, Michigan, Duke, Northwestern, and UCLA, to name a few, offer certification programs. Many manufacturers hire Lean Manufacturing (LM) experts to lead the transformation of their company. Indeed, the largest online jobs website lists 216 Lean Six Sigma jobs in the Detroit area alone on January 20, 2024 (Indeed, n.d.).

Many organizations, including universities and manufacturing companies, train students and employees in Lean Manufacturing (LM) principles using Experiential Learning (EL) methods. Simulated Factories (SFs) developed by universities and manufacturing companies utilize these facilities for training.

People and Standardization are foundational to Lean Manufacturing (LM), with Continuous Improvement (CI) driving all elements of a Lean Manufacturing (LM) system, See (Figure 1). People provide the strategic advantage of a Lean Manufacturing (LM) system, and people's role in a Lean Manufacturing (LM) system was born out of necessity. In 1949, a collapse in sales forced Toyota to terminate a large part of the workforce. Kiichiro Toyoda resigned, taking responsibility for the failure. The labor union negotiated lifetime employment, wages tied to seniority vs. job function, and profit-sharing. These changes led Taiichi Ohno to comment, "If we are going to take you on for life, you have to do your part by doing the jobs that need doing" (Womack et al., 1990, p. 54). Employees became viewed as fixed assets requiring investment. They became the primary problem solvers of the organization. With intimate knowledge of why things go wrong, autoworkers in Japan now had a voice, unlike in Detroit. Improvements made by those closest to the process became a key asset not experienced by global competitors (Womack et al., 1990).

Standardization provides the necessary control system to conduct experimentation, and Continuous Improvement (CI) is the catalyst that drives the perfection of a Lean Manufacturing (LM) system, see (Figure 1). Continuous Improvement (CI) requires experimentation to test ideas. Standardization ensures that the manufacturing system is controlled. To emphasize this point, Ohno famously stated, "Where there is no standard, there can be no kaizen" (Ohno, 2012, p. 175). Kaizen is the Japanese term for Improvement (Abdulmouti, 2020, p. 1).

The two pillars of the Lean House are Jidoka and Just-In-Time. Jidoka, or quality at the source, is a principle that requires process design that exposes quality defects at the source. This approach contradicts the ubiquitous use of end-of-line inspection in Mass Production (MP) operations. The initial idea of Jidoka was inspired by Sakichi Toyoda's invention in 1926 when Toyoda made fabrics. The Automatic Loom was designed to shut down after sensing a broken thread. The invention was considered a modern marvel in the garment industry and represented "the machine with intelligence" that exposed defects at the source of failure (Womack et al., 1990).

Simulated Factory

There are many incarnations of a Simulated Factory (SF). They range from the utilization of actual manufacturing environments to tabletop games. The desire to create this environment for Lean Manufacturing (LM) education is due to the prevailing wisdom that Lean Manufacturing (LM) is best taught in a Simulated Factory (SF) environment. Examples of Simulated Factory (SF) environments used in studies related to Lean Manufacturing (LM) are described below:

De Zan et al. (2015) implemented experiential learning methods within an Italian management company. This environment represents an actual manufacturing system. Buelhmann and Espinoza (2014) utilized a project approach to Lean Manufacturing (LM) transformation within actual manufacturing facilities. The forest products industry is the industry of focus. Ahmad et al. (2018) utilized a Simulated Factory (SF) named “AllFactory,” where students design and process a 3D printer using Lego material. Harris (2016), the instructor, builds a PVC pipe model while students document the process. The training is within a standard classroom. De Vin and Jacobsson (2017) conducted Lean Manufacturing (LM) training in a Simulated Factory (SF) that included materials processing stations and assembly. The SF is referred to as the Karstad Lean Factory. Van der Merwe (2017) applied Lean Manufacturing (LM) education within a Simulated Factory (SF) focused on Assembly Operations. Pozzi et al. (2015) trained engineering students in a Simulated Factory (SF) environment, building "go-carts" with most lean disciplines displayed. Kreimeier et al. (2014) developed a complex Simulated Factory (SF) environment to conduct experiential Lean Manufacturing (LM) training.

Witt et al. (2018) used problems students had at home to implement a 5S project. 5S is a systematic methodology originating from Japan, used for organizing, cleaning, developing, and sustaining a productive work environment. It stands for Sort (Seiri), Set in order (Seiton), Shine (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke). This approach emphasizes the importance of a clutter-free workplace, efficient storage methods, maintaining cleanliness, creating standardized operations, and fostering disciplines to maintain order. The 5S methodology is widely adopted in manufacturing, warehousing, and various service industries as a foundational element of continuous improvement and lean management practices, aiming to increase productivity, safety, and employee satisfaction (Osada, 1993). Garay-Rondero et al. (2019) involve fully implementing a Simulated Factory (SF) called the Lean Thinking Learning Space (LTLS), and Tortorella et al. (2018) compare two approaches to teaching Lean Manufacturing (LM) based on Learning Styles. The two approaches are Problem-Based Learning and Classroom Lectures.

Statement of Problem

Successful proposals to funding agencies requesting support for developing a Simulated Factory (SF) will require justification. Quantitative research supporting the efficacy of an experiential approach helps to strengthen justification. Current literature regarding the efficacy of Experiential Learning Theory (ELT) for Lean Manufacturing (LM) does not rise to the level of quantitative analysis but instead relies on qualitative methods. Much of the literature is anecdotal, reporting "incidental success stories or failed implementation of Lean Manufacturing" (De Vin et al., 2019, p. 434). Studies justified by quantitative research provide a stronger case for institutions requesting funding for a Simulated Factory (SF). Further, improved efficacy of Lean Manufacturing (LM) training for participants will support improved success for students and companies implementing and improving Lean Manufacturing (LM) systems.

Significance of the Study

Simulated Factories (SFs) are becoming prevalent worldwide. The European Network of Innovative Learning Factories (NIL) was funded by the German Academic Exchange Service (DAAD) to enhance the mobility between the leading European universities involved in the research and operation of Learning Factories (Kreimeier et al., 2014). A partnership agreement between a Southeastern University's Industrial and Systems Engineering department and the Universidad Del Norte Coquimbo Chile built a Simulated Factory (SF) that teaches Lean Manufacturing (LM).

There is a lack of literature that statistically validates, using a quantitative experimental design, the efficacy of a Simulated Factory (SF) as compared to traditional classroom lectures. Demonstrated value via quantitative experimental design would interest the growing community of educators who must validate the Experiential Learning (EL) approach due to the financial investment required to implement it.

Many organizations fund simulated factories (SFs), and the cost can be relatively high, (Fab Foundation, n.d.). While traditional labs for specific engineering disciplines are standard, Simulated Factories (SFs) are not typically found in higher education. Securing funding from granting organizations to support this expense requires a more robust justification than a traditional chemistry lab. This research takes advantage of an existing SF to demonstrate the efficacy of the experiential approach in a Simulated Factory (SF). This study can provide justification for institutions requesting funding for Simulated Factories.

This research prompts future investment to ensure students have the necessary tools to eliminate waste and redesign operating systems in the industry. Industry and students of Lean Manufacturing (LM) will benefit.

Limitations of Study

Learning through the lab experience is in addition to classroom lectures (CLELSF). A better understanding of the efficacy of experiential learning would involve students taught exclusively in a lab environment vs. a classroom lecture. Much of the data for those subjects not engaged in the Experiential approach (CL) used classroom lecture recorded video due to their distance learning status. Students engaged with Experiential Learning attended in-class lectures. Distance students are non-traditional. They typically work within industry. The (CLELSF) students include a mix of graduate and undergraduate students whereas distance students are exclusively graduate level.

Definition of Terms

A3:

A3 is a structured problem-solving and continuous improvement approach, encapsulating the entire process on a single A3-size sheet of paper. Originating from Toyota as part of the Toyota Production System, the A3 methodology identifies, analyzes, and resolves complex problems and proposes improvements and strategies. It guides users through a logical sequence of steps, from background and current situation analysis to goal setting, root cause analysis, action plan development, and follow-up. The A3 process promotes clear communication, collaboration, and rigorous problem-solving, making it a powerful tool for organizational learning and improvement (Shook, 2008).

Continuous Improvement:

Continuous Improvement in Lean, often referred to by its Japanese term "Kaizen," is a cornerstone principle of lean manufacturing that focuses on the ongoing pursuit of incremental improvements in all aspects of an organization's processes. It involves everyone from executives to front-line workers in a collective effort to enhance efficiency, quality, and customer satisfaction by systematically identifying and solving small problems before they become larger issues (Imai, 1986).

Experiential Learning Theory:

Experiential Learning Theory (ELT) is an educational framework emphasizing learning through experience. Developed by David Kolb, ELT posits that knowledge is constructed through a cyclical process of experiencing, reflecting, thinking, and acting. This theory suggests that effective learning occurs when individuals are engaged in experiences that are then reflected upon, leading to new ideas and concepts, which are ultimately tested through new experiences (Kolb, 1984).

FIFO:

FIFO, an acronym for "First-In, First-Out," is an inventory management and valuation method where goods purchased or produced first are sold or used first. This approach ensures that the oldest inventory items are recorded as sold first, which is particularly important for perishable goods or products with expiration dates to minimize waste and obsolescence. FIFO is also used in accounting to calculate the cost of goods sold and ending inventory in businesses where inventory items are indistinguishable from one another, such as chemicals or fuel (Kieso et al., 2019).

Fishbone Diagram:

The fishbone diagram, also known as the Ishikawa or cause-and-effect diagram, is a visual tool for identifying and organizing the potential causes of a specific problem or effect. Developed by Kaoru Ishikawa in the 1960s, it aids in brainstorming to uncover the root causes of an issue. The diagram resembles the skeleton of a fish, with the problem statement at the head and the bones representing different categories of root causes (e.g., People, Process, Materials, Environment). It facilitates systematic analysis and helps teams focus on the underlying factors of a problem rather than symptoms, making it a widely used technique in quality management and continuous improvement processes (Ishikawa, 1986).

Heijunka:

Heijunka is a scheduling system that controls volume and product mix to represent customer buying patterns. This leads to system flexibility, reduced waste, and improved efficiency. Heijunka reduces batching, reducing Work-in-Process Inventory and Lead Time from order to delivery (Liker, 2004).

Jidoka:

The concept of Jidoka requires process methods that prevent defects from exiting the work-station of origin. “This mechanism stops the line (or machine, etc.) when there is a problem, inducing people to take action. If the line never stops at all, that may be considered wasteful since problems remain hidden” (Suzaki, 1993, p. 165). The concern when no problems are found in the work-station is that the process does not detect all problems; therefore, some problems may be escaping the work-station. Defects exiting the station may overwhelm the system, eventually escaping and getting into the customer's hands. A weak system may rely too much on downstream inspection.

Just-In-Time (JIT):

Just-In-Time is one of the four sub-topic areas of the survey instrument. There are several lab activities designed to reinforce JIT understanding. “The Kanban system is an information system that harmoniously controls the production of the necessary products in the necessary quantities at the necessary time in every process of a factory and also among companies. This is known as Just-in-time (JIT) production” (Monden, 1993, p.15).

Kanban:

The Kanban system is an information system that harmoniously controls the production of the necessary products in the necessary quantities at the necessary time in every process of a factory and also among companies. This is known as Just-in-time (JIT) production (Monden, 1993, p. 15).

Lean Manufacturing:

Lean manufacturing is a production methodology aimed at reducing waste and increasing efficiency in the manufacturing process. It focuses on optimizing workflow, reducing inventory, and improving product quality by eliminating non-value-adding activities. Lean manufacturing principles are derived from the Toyota Production System and have been widely adopted in various industries (Petrov, 2021).

Manufacturing Cell:

A Lean Manufacturing Cell refers to a specific layout arrangement in a manufacturing environment designed to optimize workflow, minimize waste, and enhance productivity by grouping all the necessary equipment, tools, and personnel required to complete a single or a series of steps in the production process. This setup facilitates a smooth flow of materials and information, enabling quick response to customer demands and reducing lead times. The goal of a Lean Manufacturing Cell is to implement lean principles, such as just-in-time production and continuous improvement, to create a more efficient and flexible production system (Lean Enterprise Institute, n.d.).

Mass Production:

Mass production is a method of manufacturing that uses standardized parts and processes to produce large quantities of identical items. This approach typically involves assembly lines, specialized machinery, and workers assigned to specific tasks, which increases efficiency and reduces costs. Mass production is often associated with the industrial revolution and became widely adopted in the early 20th century, particularly in the automotive industry (Heizer, Render, & Munson, 2021).

Simulated Factory:

A simulated factory environment is designed to include manufacturing systems, subsystems, and practices found in an actual manufacturing operation. The simulated factory is designed to teach students about manufacturing through "hands-on" activities that enhance their learning.

Single Minute Exchange of Die (SMED):

Single Minute Exchange of Die (SMED) is a lean manufacturing process developed by Shigeo Shingo to reduce the time it takes to complete equipment changeovers dramatically. The term "single minute" refers to the goal of reducing changeover time to under 10 minutes (i.e., in the "single digits" minute range). SMED aims to minimize production downtime and increase flexibility in manufacturing processes by enabling quicker switches between product lines. This process improvement technique is critical for reducing waste, enhancing production flow, and meeting customer demand with higher efficiency (Shingo, 1985).

Standardization:

Standardization defines how products are processed via work instruction at the job station and creates the blueprint for the physical facility. 5S and Standardization are the foundation for control and experimentation for continuous improvement. Taiichi Ohno, the Toyota executive credited with developing the Toyota Production System or Lean Manufacturing, famously said, "Where there is no standard, there can be no kaizen" (Ohno, 2012, p. 175). Kaizen is the Japanese term for Continuous Improvement.

Standard Work:

Establishing precise procedures for each operator's work in a production process, based on three elements:

1. Takt time, which is the rate at which products must be made in a process to meet customer demand.
2. The precise work sequence in which an operator performs tasks within takt time.
3. The standard inventory, including units in machines, required to keep the process operating smoothly. (Lean Enterprise Institute, n.d.)

Supermarkets:

In Lean Manufacturing, supermarkets refer to a controlled inventory storage area or a buffer that holds a specific amount of materials or products between production stages. The purpose of a supermarket is to regulate the flow of materials, ensuring a smooth and continuous production process by providing immediate access to necessary items without causing delays or overproduction. This concept is part of a material pull system, where downstream processes draw from the supermarket only what is needed based on customer demand, thereby reducing waste and improving efficiency. Supermarkets help achieve better inventory management, minimize excess stock, and align production more closely with actual demand (Womack & Jones, 2003).

Toyota Production System (TPS) or Lean Manufacturing (LM):

Lean Manufacturing (LM) consists of maintaining the interdependence of all elements and, most importantly, the role people play in the process. Jeffrey Liker (2004) explains:

> The Toyota way includes tools designed to support people continuously improving and continuously developing. For example, one-piece flow is a very demanding process that quickly surfaces problems that demand fast solutions, or production will stop. This suits Toyota's employee development goals perfectly because it gives people the urgency to confront business problems. The view of management at Toyota is that they build people, not just cars. (p. xvi)

Value Stream Mapping:

Value Stream Mapping (VSM) is a lean-management method used to analyze and design the flow of materials and information required to bring a product or service to a consumer. It helps identify and eliminate waste, thereby streamlining production processes. VSM provides a visual representation of all the steps and data involved in a process, from start to finish, highlighting areas for improvement (Rother & Shook, 2003).

5S:

5S is a systematic methodology from Japan, used for organizing, cleaning, developing, and sustaining a productive work environment. It stands for Sort (Seiri), Set in Order (Seiton), Shine (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke). This approach emphasizes the importance of a clutter-free workplace, efficient storage methods, maintaining cleanliness, creating standardized operations, and fostering disciplines to maintain order. The 5S methodology is widely adopted in manufacturing, warehousing, and various service industries as a foundational element of continuous improvement and lean management practices, aiming to increase productivity, safety, and employee satisfaction (Osada, 1993).

5 Whys:

The 5 Whys analysis is a problem-solving technique to explore the underlying cause-and-effect relationships behind a particular problem. Originating from the Toyota Production System, it involves asking the question "Why?" five times (or as many times as needed) to drill down to the root cause of a problem, starting from a symptom and progressively uncovering layers of issues. This iterative questioning technique helps identify a problem's fundamental cause, enabling effective solutions. The 5 Whys analysis is a simple yet powerful tool for troubleshooting, quality improvement, and lean manufacturing processes, emphasizing a deeper understanding of problems to prevent their recurrence (Ohno, 1988).

Organization of the Study

Chapter 1 introduces the purpose of the study, research questions, Adult Education, Lean Manufacturing, statement of the problem, the significance of the study, and the limitations. Chapter 2 literature review highlights the use of Simulated Factory environments in Higher Education, designed to employ experiential learning methods to improve the teaching efficacy of Lean Manufacturing education. Chapter 3 describes the data, independent sample groups, and methods used to conduct the research. Chapter 4 describes the findings when comparing independent sample group test data between those with classroom lecture and lab experience (CLELSF) vs those without (CL). Chapter 5 discussed opportunities for further research that can address this study's unanswered questions.

CHAPTER 2. Review of Literature

Introduction

This literature review involves Experiential Learning within a Simulated Factory (SF), teaching Lean Manufacturing (LM) principles. Researchers primarily relied on anecdotal evidence to demonstrate efficacy. In addition to related research in the literature, a discussion of Adult Education, Experiential Learning Theory, and Lean Manufacturing is presented as context for this study. Three subtopic areas of Lean Manufacturing (LM) are measured: Jidoka, Just-In-Time, and Standardization.

A common approach to validating learning in this literature review was student surveys, which gauged students' impressions regarding what they felt they learned or how they enjoyed the educational experience. Quantitative evidence showing the effectiveness of Experiential Learning (EL) in teaching Lean Manufacturing (LM) in a Simulated factory (SF) is limited or nonexistent. Quantitative vs. qualitative analysis of efficacy is preferable to ensuring knowledge and understanding of sub-topic areas of instruction that could be improved.

Purpose of Study

A validated Experiential Learning (EL) approach in teaching Lean Manufacturing (LM) principles improves student knowledge. It ensures that students going to industry understand and can apply the Lean Manufacturing (LM) tools required to eliminate waste and redesign operating systems. Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165). This study also supports educators in making a case for Simulated Factories (SF) to funding agencies.

When teaching Lean Manufacturing (LM), the importance of the Just-In-Time (JIT) sub-topic is clear, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation, Rother et al, 2003). The hesitancy of managers to utilize this most important tool is an integral part of this study leading to the formulation of one of the three research questions, which focused on Just-In-Time (JIT) knowledge with 16 questions of a 47-question survey related to Just-In-Time (JIT). These 16 questions were administered to independent sample groups: students engaged in classroom lectures and experiential learning in the Simulated Factory (CLELSF) and students with classroom lectures (CL) only.

The 47 questions survey represents four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10) and JIT (16). The questions are designed to test for differences between On-Campus and Distance students. It was expected that students engaged in (CLELSF) would show improvement in all sub-topic areas of Lean Manufacturing (LM) with more significant improvement in Just-In-Time (JIT) knowledge over students with (CL).

Research Questions

The following research questions were posed in the study:

RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

RQ3: Is there a performance difference between "On-Campus" students and "Distance" students?

Overview

Distance students represented the Classroom Lecture only (CL) or "No Lab" independent sample in this study. In contrast, On-Campus students represented Classroom Lecture and Experiential Learning in a Simulated Factory (CLELSF). Distance students are not on campus. They view recorded lectures as convenient for their schedules. Due to their age, experience, and responsibilities, distance students can be considered adult learners (See Table 1).

Table 1

Student demographics – On-Campus vs. Distance

Survey Response	On-Campus	Distance
Married	7%	47%
Full Time Employed	16%	100%
Children	9%	41%
25 years of age or older	11%	94%
Lean Experience prior to class	41%	83%

Note: Limited survey based on 17 Distance students vs. 46 On-Campus

In one data set of this study, On-Campus students represent both the Independent Sample (CL) and (CLELSF) due to a COVID isolation period in which lab activities were canceled. This particular data set measured the JIT sub-topic of survey questions only. This was significant because the risk of confounding data from two student types was eliminated, albeit for one sub-topic area of (LM).

Adult Education

Traditional pedagogical methods of instruction evolved from the seventh and twelfth centuries in the monastic schools of Europe. The methods became prevalent in secular schools as well in the twelfth century as universities developed. The word pedagogy was derived from the Greek word for leading a child. Pedagogy can be best described as the art and science of teaching children (Knowles, 1980, p. 40).

Educators from 1929 to 1948 abandoned traditional pedagogical methods because they noticed problems. Pedagogy was premised on the conception of the purpose of education - namely, the transmittal of knowledge and skills that had stood the test of time – that adult learners seemed to sense was insufficient. Accordingly, their teachers found them frequently resistant to the strategies that pedagogy prescribed, including fact-laden lectures, assigned readings, drills, quizzes, rote memorization, and examinations. Adults appeared to want something more than this, and drop-out rates were high. (Knowles, 1980, p. 41).

The philosopher Alfred North Whitehead surmised that for the first time in history, the longer life expectancy of the 20th century extended beyond the knowledge required for an era. This led to the need for lifelong learning and the ability to seek out knowledge to adapt (Knowles, 1980, p. 41). Adult Education developed out of this need. Adult Education theory identifies Andragogy as the art and science of helping adults learn.

Characteristics of Adult Learners

Adult learners have more experiences when entering an educational setting than non-adult learners. Their experiences become intertwined with their identity as a person. Because of this, it is advantageous to utilize their expertise in the educational process. If their experience is discounted or ignored, they may deem the educational process an affront to their person (Knowles, 1990, pp. 58–60).

Lindeman places great value on the experience of adults. According to Lindeman, "adult experience is already there waiting to be appropriated. Experience is the adult learner's living textbook" (Lindeman, 1926, p. 10). Lindeman believed that adults benefit from active involvement in determining what, how, and when to learn. Lindeman (1926, pp. 4–7).

Knowles (1980) believed that as individuals mature, 1) their self-concept moves from dependency to self-directedness; 2) their growing experience supports learning; 3) they focus learning toward their social roles, and 4) they desire to use newfound knowledge rather than delay the application immediately. Knowledge becomes performance vs subject-based.

Traits of Adult Learners

Knowles, Holton, and Swanson (2015) identified the following traits for adult learners:

- Self-direction: Adult learners typically prefer to take responsibility for their own learning, showing a strong sense of self-direction.
- Experience: They bring a wealth of life experiences that they use as a resource for learning.
- Readiness to Learn: Adults often seek learning experiences that are relevant to their current life situations and are ready to learn things that they feel will help them in real-life tasks.
- Orientation to Learning: They tend to be problem-centered rather than content-centered in their learning orientation, seeking education that is directly applicable to their work or personal life.
- Motivation: While external motivators (such as promotions or job security) are essential, adult learners are often more motivated by internal factors like personal growth and satisfaction.

Table 2

Andragogy vs Pedagogy

Number	Aspect	Pedagogical Model	Andragogical Model
1	Need to know	Learners need to know what the teacher tells them.	Learner need to know why something is important prior to learning it.
2	The learner's self-concept	Learner has a dependent personality.	Learners are responsible for their own decisions.
3	The role of the learner'	The learner's experience is of little worth.	The learner's experience has great importance.
4	Readiness to learn	Learners become ready to learn what the teacher requires.	Learners become ready to learn when they see content as relevant to their lives.
5	Orientation to learning	Learners expect subject-centered content.	Learners expect life-centered content.
6	Motivation	Learners are motivated by external forces.	Learners are motivated primarily by internal forces.

Source: Knowles et al. 1998

Experiential Learning

Kolb (1984) defined learning as the process whereby knowledge is created through the transformation of experience. Knowledge results from a combination of grasping and transforming experience. Kolb (1984) indicated that Experiential Learning Theory fundamentally differs from Behavioral and Cognitive learning theories. Kolb further explained that the term experiential is used for two reasons: it is tied to the work of Piaget, Dewey, and Lewin and the central role experience plays in the learning process. This differentiates ELT from rationalists and other cognitive theories of learning that tend to give primary emphasis to acquisition, manipulation, and recall of abstract symbols and from behavioral learning theories that deny any role for consciousness and subjective experience in the learning process (Kolb, 1984).

Lewin believed much of organizational ineffectiveness is related to inadequate feedback—the lack of feedback results from an imbalance between observation and action. Either the individual or organization emphasizes decision and action at the expense of information gathering or from a tendency to become “bogged down” by data collection and analysis. By striking a balance between the two, effective, goal-directed learning and action can occur (Kolb, 1984). Dewey’s model is similar to Lewin's. Dewey believed the feedback process provides learning that creates impulses, feelings, and desires of experience into higher-order purposeful action (Kolb, 1984).

Piaget’s Model of Learning and Cognitive Development indicated that experience and concept, reflection and action form the basic continua for the development of adult thought (Kolb, 1984). Piaget (1970) pointed out that these have been the major directions of development in scientific knowledge. The learning process whereby this development takes place is a cycle of interaction between the individual and the environment that is similar to the learning models of Dewey and Lewin (Kolb, 1984).

There is a similarity among the three learning process models of Piaget, Dewey, and Lewin. Taken together, they form a unique perspective on learning and development. This perspective can be characterized by the following propositions, which are shared by the three major traditions of experiential learning:

- Learning is best conceived as a process, not in terms of outcomes
- Learning is a continuous process grounded in experience
- The process of learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world. (Kolb, 1984)

Learning is described by the three theories discussed, and experiential learning theory treats learning as process vs outcome. Learning as a process is continuous and changing based upon the constant interaction one has with the environment and the adjustment of understanding based upon the accumulation of knowledge and the changing environment. All three learning models highlight a conflict that requires resolution to adapt. A key point of contrast Kolb makes is:

> When viewed from the perspective of experiential learning, the tendency to define learning in terms of outcomes can become a definition of non-learning, in the process sense that the failure to modify ideas and habits due to experience is maladaptive. The behaviorist axiom that the strength of a habit can be measured by its resistance to extinction. The more I have learned a given habit, the longer I will persist in behaving that way when it is no longer rewarded. (Kolb, 1984)

Experiential Learning Theory (ELT) defines learning as the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience (Kolb, 1984).

There are four modes of ELT:

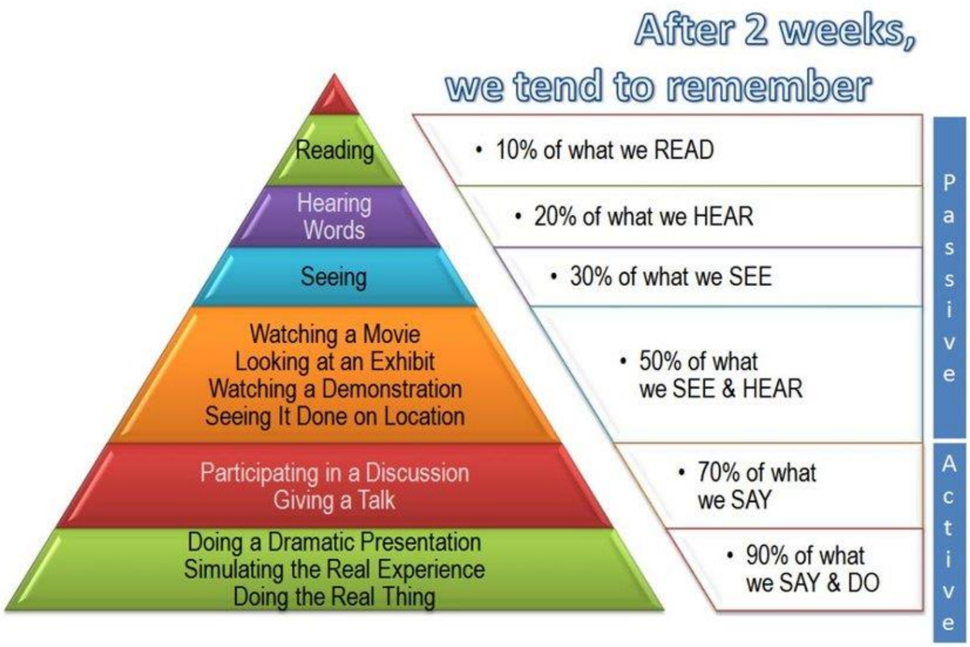
- Concrete Experience (CE)
- Abstract Conceptualization (AC)
- Reflective Observation (RO)
- Active Experimentation (AE).

The first two modes are experienced-based, while the last two modes are transformative (Kolb, 1984).

Dale's Cone of Experience best illustrates Edgar Dale's emphasis on experiential learning (See Figure 2). Dale (1969) revealed that the most effective learning process provides as many links to practical and concrete processes as possible.

Figure 2

Cone of Experience



There is evidence that Experiential Learning improves retention of knowledge.

A longitudinal study explored the degree to which a required MBA course emphasizing experiential learning positively influenced student retention. Results from subgroup comparisons across multiple time periods suggest that this teaching methodology enhances retention effects. The improved retention was attributed to the experiential emphasis on social integration and corresponds to one of Tinto's (1993) three principles associated with effective college retention (Prussia & Weis, 2003-2004, p. 403).

Forte-Celaya et al. (2020) researched long-term knowledge retention using project/challenge-based experiential methods. The engineering students involved showed a higher level of knowledge retention compared to traditional educational methods. Although the data was limited to 25 students involved with project challenged-based experience vs. 16 involved in traditional classroom methods, results showed a significant advantage when tested for the project/challenged-based students.

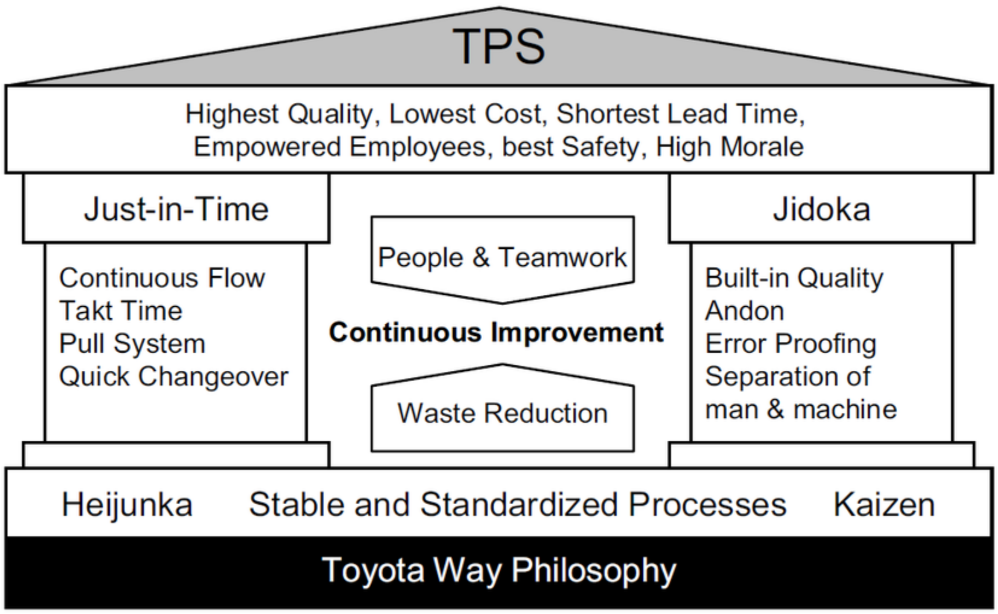
Lean Manufacturing

Lean Manufacturing (LM) represents the third generation of manufacturing after the Job Shop and Henry Ford's Mass Production System (Black & Phillips, 2013). The term LM was coined in the book The Machine That Changed the World (Womack et al., 1990). It is synonymous with the Toyota Production System (TPS). Taiichi Ohno, the Executive Vice President of Toyota from 1975 – 1978, is considered the Father of TPS.

Lean manufacturing (LM) is an operating system that continuously drives waste elimination. The elements that make up the discipline of LM are illustrated in the "Lean House" (Figure 3).

Figure 3

The Lean House, Representing the Toyota Production System (TPS)



JIT is complicated to teach in a traditional classroom environment. Taiichi Ohno sent Senior Managers who were not up for promotion to supplier locations to teach JIT. Past teaching attempts failed, and Ohno concluded it must be taught while implemented at the supplier location (Ohno, 1988). Jim Womack, the author of "*Lean Thinking*," indicated that Value Stream Mapping (VSM), a tool of JIT, is the most important step in lean transformation and the step most often skipped in the 10-step process (Rother et al., 2003).

Although the explanation of importance is communicated, the inability or drive to understand and apply it limits successful implementation. Two primary reasons for this phenomenon may be:

1) **Human pre-disposition**. The JIT sub-topic of Lean Manufacturing forces a continual drive toward zero inventory. This places the organization at risk of shortages and profit loss or, worse, loss of business. While it is necessary to eliminate the massive waste inherent in Mass production systems, the discipline brings out the intrinsic fear of catastrophe. This behavior can

be observed when people park cars back into the parking space. While it takes more thought and time to go between two vehicles than to back out, the sense of being ahead satisfies basic instincts.

> Hoarding can be seen as an adaptive behavior that stems from our ancestors' need to survive in environments where resources were scarce and unpredictable. This behavior ensured that individuals had sufficient supplies during periods of scarcity. Evolutionary psychologists suggest that this trait may have been naturally selected because those who hoarded resources had a higher survival rate during tough times, thus passing on these traits to their offspring (Barber, 2019).

2) **Traditional measures of manufacturing success.** Financial goals focused on short-term results (monthly) will drive behaviors that counter Lean Manufacturing waste reduction initiatives. To further exasperate the problem, bonus structures that reward short-term goals become the organization's driving force vs. long-term system improvement.

Wilson (2009) identified 10 Lean Manufacturing killers and they include Lean Killer 6 “Have a Short-Term View of Success, Focused Narrowly on Financials” and Lean Killer 7, “Have in Place a Financial Reward System for Individuals That Is Not Supportive of Lean” (pp. 15-16).

These phenomena relative to the sub-topic of JIT led to research question number 2, RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

Experiential Learning Research – Lean Manufacturing

Lean Manufacturing (LM) has many sub-topic areas. The sub-topics identified in the lean house are JIT (which includes SMED, Work Cells, Kanban, Value Stream Mapping, and Supermarkets), Jidoka (Quality at the source), Standardization (which includes 5S), Continuous Improvement, and People / Teams. Most of the cited work does not indicate a sub-topic area of focus and, therefore, is assumed to cover all broad areas of LM.

Witt et al. (2018) focused on the 5S discipline of LM. 5S is a form of standardization that relates the overall manufacturing facility vs. a specific process. Harris (2016) focuses on the seven wastes inherent in all aspects of LM. The students in this study were K-12 teachers, and it was hoped they would take what they learned back to the classroom to reduce waste in the system.

Ahmad et al. (2018), Buehlmann and Espinoza (2014), De Vin and Jacobsson (2016), De Zan et al. (2015), Garay-Rondero et al. (2019), Kreimeier et al. (2014), Pozzi et al. (2015), Tortorella et al. (2018), and Van der Merwe (2017) indicated that there were multiple LM areas that need to be considered for research. Ahmad et al. (2018) included all sub-topics of LM; they emphasize the sub-topic Value Stream Mapping, an element of JIT, and teach Enterprise Resource Planning (ERP) and Industry 4.0 (Cyber-physical systems).

Table 3

Lean Sub-Topics Focus of Studies

Lean Sub-Topic	Focus of Study
Standardization / Standard Work / 5S	1
Jidoka – Quality at the Source	0
JIT – (VSM, SMED, Kanban, Supermarkets)	1
Continuous Improvement	0
Seven Wastes (MUDA)	1
Problem Solving Tools	0
People / Teams	0
All areas of Lean	10

Student Types

These studies' primary two groups of students were from industry and college. College students were typically in engineering programs. Industry students ranged from lower-level employees who worked the process or senior managers responsible for implementing change.

Tortorella et al. (2018) focused their research on graduate industrial engineering students in the Department of Industrial Engineering, Federal University of Santa Catarina, Florianopolis, Brazil. Buelhmann and Espinoza's (2014) participants were Virginia Tech engineering students. The number of students participating was relatively low. Only 3-5 students were admitted into the program annually, and total team membership fluctuated between 6-14. Membership was voluntary.

Witt et al. (2018) involved Information Technology college students in an undergraduate operations supply chain management course at California State University. Ahmad et al. (2018) taught graduate and undergraduate students at the University of Alberta. Harris (2016) instructed LM to MBA students who were K-12 schoolteachers at the University of Indianapolis.

Van der Merwe (2017) taught LM to engineering students at the Nelson Mandela Metropolitan University in Port Elizabeth, South Africa. De Zan et al. (2015) schooled industrial employees in an actual manufacturing system. De Vin and Jacobsson (2016) involved industrial employees from manufacturing and healthcare organizations.

Pozzi et al. (2015) study was directed toward engineering students at the Institute of Technology, Università Carlo Cataneo, Castellanza, Italy. Kreimeier et al. (2014) taught both Ruhr – Universität Bochum, Germany students and industry members. Garay-Rondero et al. (2019) exclusively involved industrial engineering students.

Table 4

Student Types by Study

Student Type	Engineering	Business	IT	Other	Hourly	Salary	Total
College	6	1	1	1	0	0	9
Industry	0	0	0	0	2	1	3

Experiential Model Utilized

Experiential learning appears to be assumed simply by engaging students in hands-on activities. A few researchers specifically cite a model as a guide to teaching methods.

De Zan et al. (2015) used a case study design. The case study requires gathering data about the company and testing a proposed theory using face-to-face interviews and observations. The study recommended setting up a Lean training system that specifies the content (content analysis) and the content and the process (experiential analysis).

In the development of design, the authors used Kolb's experiential learning theory structure (Kolb, 1984);

(1) Concrete Analysis

(2) Reflective observation

(3) Abstract conceptualization

(4) Experimentation

Tortorella et al. (2018) used two approaches: Lean Manufacturing Practices (Classroom lectures, team exercises, group participation, case studies, and short games) and Lean Manufacturing Problem-Based Learning with coaching, mentoring, and hands-on activity. These two approaches were necessary to compare Learning Styles to the approach.

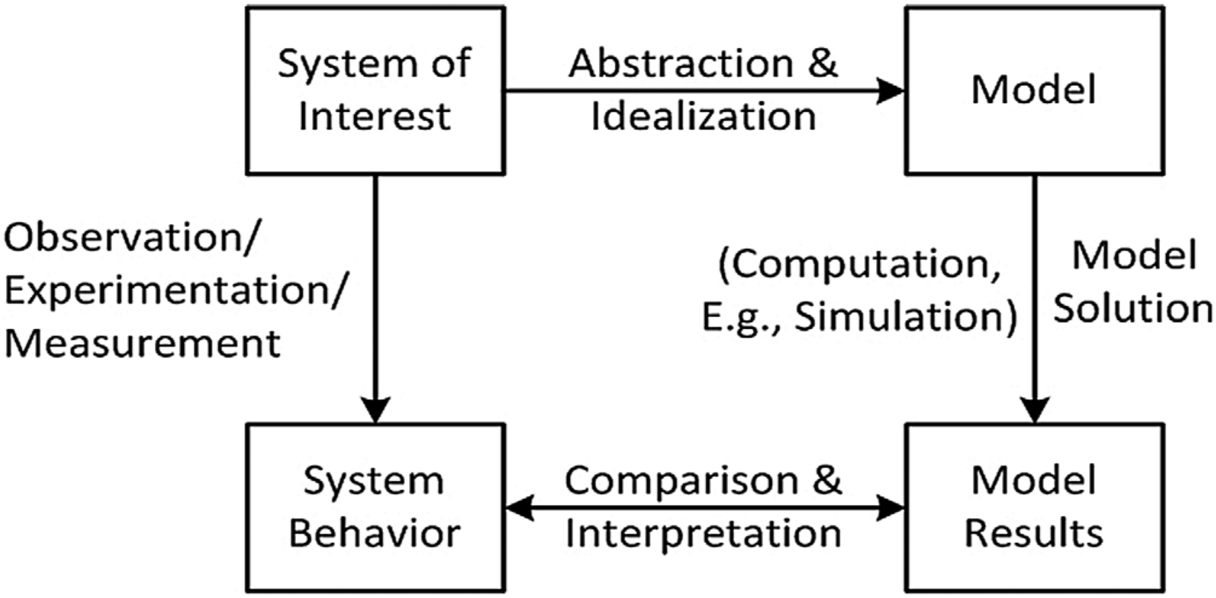
Buehlmann and Espinoza (2014) identified lean transformation projects within manufacturing operations. The projects were student-driven with faculty support. Students also taught industry participants the principles of lean manufacturing.

Witt et al. (2018) designed their curriculum using Kolb's Experiential Learning Cycle. Students were not given industrial projects to resolve; instead, they were asked to identify problems in their personal lives to apply the 5S discipline. The curriculum identified the process to complete Kolb's learning theory structure of concrete analysis, reflective observation, abstract conceptualization, and experimentation.

De Vin and Jacobsson (2016) used a model called SoI, or System of Interest, to optimize the educational design (see Figure 4).

Figure 4

System of Interest (SoI) and Model (PROSPEC, 2002).



Source: Prospec, (2002).

Harris (2016) created a model truck made of PVC piping for assembly. The truck has four models and is scheduled by Kanban cards. Students must identify Value-Added, Waste, and Incidental work. Their goal was to eliminate waste and reduce incidental work. The simulation is effective and identified as experiential learning, although no model is used as a framework in the educational design.

Ahmad et al. (2018) utilized a project-based approach to reconfigurable manufacturing systems. However, they did not specifically identify an experiential model used to develop their approach to teaching the discipline of LM. Van de Merwe (2016) identified the educational design as experiential but did not specifically identify a model such as Kolb's Experiential Learning Theory.

Pozzi et al. (2015) discussed the importance of experiential learning and implemented a form of experiential learning that does not follow a formal model. Kreimeier et al. (2014) did not follow a formal experiential learning model.

Garay-Rondero et al. (2019) developed a hybrid model combining Experiential Learning and challenge-based learning. The author cites Kolb's experiential learning cycle and identifies challenge-based Learning (See Table 5).

Table 5

Comparison of Challenge-Based, Problem-Based, and Project-Based Learning

Issue	Challenge-Based Learning	Problem-Based Learning	Project-Based Learning
Problem	The relevant issue in the social, economic, or environmental context. It is open, and it may even be undefined	Relevant according to a subject, usually fictitious	Relevant, already defined an delimited by the project manager
Solution	Demands an urgent real solution, applicable and verifiable. Requires a product and / or service implemented with concrete actions and effectiveness, defined by the objectives set.	No real urgent solution is required. A solution or product proposal that demonstrates the learning processes is enough.	A real solution is expected (which may already be pre-directed) but not necessarily urgent. It can be a product, presentation, or implementation.
Actors	Stakeholders and experts according to context: Coaches, mentors, professors, researchers, etc., as support for the student	Professor(s)	Professor and/or project manager

Source: Garay-Rondero et al. (2019)

Only four of the eleven research studies cited a defined experiential model for designing their curriculum. Two use Kolb's ELT model, while two others use a hybrid model. Seven used the term experiential in a generic way to mean some form of hands-on approach.

Rationale for Experiential Approach

The rationale for using an experiential approach varies among researchers. De Zan et al. (2015) intended to present a framework that can be used to assess the experiential learning processes of Lean M anufacturing education in an innovative learning environment. This answers their research question, “How is it possible to assess an experiential learning process?” Their purpose was not directly focused on Lean Manufacturing training but on identifying an optimal approach for designing the training system.

Tortorella et al. (2018) found that learning styles did apply to Lean Manufacturing (LM) education. They also acknowledged the value of experiential methods by indicating that although teaching LM has significantly evolved over the past decades, the single application of traditional teaching methods jeopardizes learning effectiveness of graduate students because of the practical nature of Lean Manufacturing.

Due to forest industry needs and the interest in Lean Manufacturing as critical training, Buehlmann and Espinoza (2014) examined some educational programs that have formally incorporated the teaching of lean concepts in the curricula. One program was located in Virginia Tech which took on the challenge of getting students “actively involved in learning, applying, and reflecting on LM principles” (p. 2).

Witt et al. (2018) were motivated by the dissatisfaction with graduate students' competence within the Information Systems domain. They found that teaching complex concepts required an understanding of integrated business processes.

Ahmad et al. (2018) identified the need for reconfigurable systems driven by the rise of Industry 4.0. Further, they identified a common problem students face when entering an industrial environment. Traditional teaching methods have not been able to provide the overall skillset wanted in industrial applications. To address this issue, programs/environments that promote experiential learning have become more popular in post-secondary education. They also used a hands-on Simulated Factory approach to support the development of new courses for engineering students based on experiential learning techniques.

Harris (2016) asserted that experiential learning was superior to traditional teaching methods and that teachers must solve waste problems within their profession. De Vin and Jacobsson (2017) chose a Simulated Factory due to the type of students (industrial employees) who believe that a more realistic environment is required. They claim that students from industry were more used to intuitive learning than to formal instruction.

Van der Merwe (2017) was interested in determining the efficacy of experiential learning in a Simulated Factory environment. Pozzi et al. (2015) referred to the literature on the value of experiential gaming and considered that it stimulates curiosity and discovery learning, encouraging students to participate and interact actively. The authors reflected that it seems to be an effective training method, able to reinforce Lean concepts better than other training.

Kreimeier et al. (2014) indicated that learning factories have been developed to impart substantial knowledge about improvement process concepts and methods to seminar participants within a real-world manufacturing environment. Garay-Rondero et al. (2019) identified industry's demands, students' dissatisfaction with student capability, and students' failure to understand the relevance of their studies and how they relate to future industrial requirements of the job.

In this section, two studies cited industry disappointment with student capability, while three specifically stated that experiential methods were more effective than traditional classroom methods. Five others implied the superiority of the experiential approach but did not explicitly state it. For the two citing industry disappointment with traditional students, one can infer that the experiential approach was chosen because it was considered superior. The overwhelming consensus of these studies was driven by the idea that experiential learning methods are superior to traditional classroom methods.

Research Questions Posed by Researchers

In this review of literature, an analysis of the research questions that were used in each of the studies was accomplished. The analysis began by examining the various experiential methods and the purpose of each study. While many of the referenced studies did not explicitly state a research question, the intent is alluded to in the narrative. Two questions from one study were RQ1 “How is it possible to assess an experiential learning process” and RQ2 “How is it possible to measure the consistency of the learning content (lean learning) and the learning process” (De Zan et al., 2015, p. 333).

This current study's RQ1 research question may answer the first question: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Garay-Rondero et al. (2019) identified two research questions which were: RQ1 How to develop an experiential learning space for the development of relevant, personal and disciplinary competencies that impact the improvement and optimization of design processes and products in professional practice? RQ2 Could the teaching of improvement and process optimization centered around an interactive learning challenge within a flexible and experiential space contribute to the development in future engineering graduates the abilities that are highly demanded in industry, as defined by student outcomes “c” declared by ABET: “the ability to design a system, component or process to meet the desired needs within realistic limitations such as economic, environmental, social, ethical, health and safety, manufacturing and sustainability.

Only two of the eleven studies posed research questions. This study's research questions are similar to those identified.

Lean Manufacturing Training Facilities

Training methods of providing a hands-on activity for experiential learning were described in the following studies:

De Zan et al. (2015) implemented experiential learning methods within LEF, an Italian management company. The environment represents an actual manufacturing system.

Buelhmann and Espinoza (2014) utilized a project approach to LM transformation within actual manufacturing facilities. The forest products industry was the industry of focus. Ahmad et al. (2018) utilized a Simulated Factory named “AllFactory,” where students designed and processed a 3D printer using Lego material.

Harris (2016) studied an instructor that built a PVC model pertaining to Lean Manufacturing while students documented the process. The training took place in a standard classroom.

De Vin and Jacobsson (2017) conducted Lean Manufacturing training in a Simulated Factory, including materials processing stations and assembly. The Simulated Factory was referred to as the Karstad Lean Factory.

Van der Merwe (2017) applied Lean Manufacturing education within a Simulated Factory focused on Assembly Operations. Pozzi et al. (2015) trained engineering students in a Simulated Factory environment, building go-carts utilizing Lean Manufacturing disciplines.

Kreimeier et al. (2014) studied Learning Styles in classroom settings and gaming methods to understand the best approach for teaching Lean Manufacturing. Witt et al. (2018) used problems that students had at home to implement a 5S project. Garay-Rondero et al. (2019) conducted a study that involved fully implementing a Simulated Factory called the Lean Thinking Learning Space (LTLS).

Tortorella et al. (2018) compared two approaches to teaching Lean Manufacturing based on learning styles: Problem-Based Learning and Classroom Lectures. These approaches are similar to this study in that they involve traditional classroom lectures and experiential learning in a Simulated Factory. The authors used the Index of Learning Style (ILS) questionnaire (Felder & Soloman, 2004).

All the studies cited use some form of hands-on, active learning. Two used actual manufacturing facilities, and six used Simulated Factory environments.

Validation of Learning

In this section, a review of each researcher's methods that they used to validate learning or the value of the experiential approach was conducted for this literature review. Tortorella et al. (2018) validated the differences between learning styles applied to Lean Manufacturing using multivariate methods and demonstrated the effectiveness of Learning Styles paired with appropriate teaching methods. De Zan et al. (2015) did not provide evidence of any validation of the knowledge or training received by the participants.

Buelhmann and Espinoza (2014) indicated that only anecdotal evidence of learning existed. One explanation was that the results showed that students were highly motivated and became self-driven agents through the opportunity to be a member of a high-performing team and to contribute to the team's success. In addition, the LeanTeam process brought forth the best in experiential learning. Supporting faculty and team customers alike have been supported by the quality of the student's work and the professionalism and determination shown.

Witt et al. (2018) measured the 5S knowledge that students gained from the training. They did not conduct further validation of the approach that used experiential learning.

Harris (2016) revealed that learning was not validated in the study. While improvements were made by eliminating waste and redesigning the process of building a PVC truck model, it appears to have been a group effort with no evidence of testing individual knowledge.

De Vin and Jacobsson (2016) showed no evidence of learning. The study focused on the Simulated Factory and theoretical aspects of educational design. Van der Merwe (2017) offered only anecdotal evidence of efficacy for the engineering students trained within the Simulated Factory. Students believed that their grasp of the fundamental lean concepts had been significantly enhanced through exposure to the SF teaching exercises. The outcome of this initial study was endorsed by the second study's findings that measured the perceptions of their industry mentors after a six-month experiential learning period.

Pozzi et al. (2015) pointed to the results of the metric improvement: Safety, Quality, Delivery, and Cost (SQDC) as evidence of learning. SQDC is the primary metric of a Lean Manufacturing system. They did not show individual testing results of student performance.

Kreimeier et al. (2014) identified Learning Styles and evaluated their effectiveness when teaching Lean Manufacturing with games and classroom lectures. A Simulated Factory was not used, and there was little evidence of Experiential Learning methods. Quantitative methods were used, but the sample size was small: "The small sample size used in this study jeopardizes the test of a full factorial model that verifies higher-order interactions" (p. 350).

Ahmad et al. (2018) showed no evidence of learning or validation of the experiential approach. Garay-Rondero et al. (2019) was the best example of validation using statistical methods. The control and experimental groups were students taught in the traditional classroom lecture and those taught in the Simulated Factory. The results showed significant improvements related to Lean Thinking Space. However, they did not validate against a null hypothesis. Therefore, they cannot state that the results were likely not due to chance. The sample size was too small for statistical power (See Table 6).

Seven of the studies cited did not attempt to validate an experiential approach or that learning occurred. One statistically quantified learning and only used anecdotal evidence to validate learning.

While all studies cited endorsed the experiential approach directly or indirectly, only two validated the method, one anecdotally and one statistically. In a similar study, Garay-Rondero et al. (2019) set up an experiment to show the difference between classroom instruction and experiential learning. The researchers demonstrated a significant difference; however, due to the small sample size, they failed to meet a confidence level of α=.05.

Table 6

Descriptive Statistics for the Students' Competence Level Experiment

Type of Learning Space	Traditional Classroom	Lean Thinking Space
N	20	20
Mean	2.65	3.413
Standard Deviation	0.792	0.558
Min	1.5	2.5
Q1	2.063	3
Median	2.5	3.25
Q3	3.5	4
Maximum	3.75	4
Range	2.25	1.5
Mode	2.25,3.5	3,4

Source: Garay-Rondero et al. (2019)

Experiential Learning Research - Other

A review of studies that used experiential learning methods was conducted. Studies were found in the following areas:

Plant Sciences: Bauerle and Park (2012, p. 715) studied the impact of a new course, "The Nature of Plant," using experiential methods. The course involved trips to a local natural area, which included tree climbing. The activity resulted in improved homework scores.

Mechanical Engineering: Li, Öchsner, and Hall (2019, p. 283) examined the mechanical engineering course "Design of Machine Elements" which had been redesigned to include an experiential learning element. Students considered the course difficult. Students worked in teams to consider a design alternative to a gearbox. Student teams followed a Do, Observe, Think, and Plant structure. Course survey results indicated an improvement in student engagement.

Geography: Healey and Jenkins (2000, p. 185) reviewed first-year geography students that had been exposed to experiential learning theory and encouraged to consider the approach in their studies. The training was structured to recognize individual learning styles. Case studies were based on real examples written to use Kolb’s Experiential Learning Theory.

Architecture: Erbaş (2023, p. 298) was involved in a study to understand the impact of construction internships exposing students to the role of the construction site manager. The position was meant to be a model for students to aspire to. Kolb's experiential learning theory was used as the theoretical framework. Several questions were asked of participants:

> (1) Does the internship experience affect students' perception of Construction Site Managers (CSMs)? (2) Does it influence their career goals related to CSM positions? (3) Does the internship experience alter the career aspirations of intern students regarding a career as a construction site manager? and (4) Do students perceive CSMs as role models after completing their internships?

Ninety-three architecture students were involved in the study. The findings showed how internships significantly affected students, improving their comprehension of the CSM role, influencing their career aspirations, and offering life-changing experiences.

Simulated Factory (SF)

For the current study, the Lego Lab at a Southeastern U.S. university is a 4000 sq ft. facility designed to simulate a manufacturing environment to teach all Lean Manufacturing best practices. The Lego Lab comprises 15 workstations (two sub-assembly cells with five stations per cell and one moving straight-line conveyor with five stations).

A JIT-sequenced supplier produces parts in the “War Eagle” lab, which consists of five CNC machining centers and a 3D printer. The raw material is stored in an Auto Storage and Retrieval System (ASRS) and pulled to a Supermarket. Students are trained in both classroom lectures and the Lego Lab facility. Lessons learned in the classroom are demonstrated within the facility. The Lego Lab has two goals: to graduate students with ten years of manufacturing experience and to teach local manufacturers. Several company Senior Management teams, including Borbet, Brose, Hartzel Aviation, and Honda, have been trained within the Lego Lab.

Lego Lab History

Early in 2009, members of the Industrial and Systems Engineering program identified an opportunity to improve the readiness of our manufacturing-focused students for their initial industrial assignments. This recognition of need can be attributable to a concern for student readiness when entering industry and the continuous improvement requirements of ABET. A thriving academic program requires faculty to evaluate their curriculum for weaknesses and identify improvement opportunities.

The Industrial and Systems Engineering department benefited from significant lab space when new buildings were completed. The basement space available had 4,000 square feet of lab space. While much of the lab's infrastructure was incomplete (gravel vs. concrete flooring, etc.)., the possibilities were evident. A proposal to install concrete flooring and other infrastructure was required for a proper lab.

After lab improvements were complete, a case was made for an industry-manufacturing expert to utilize the lab for experiential student learning. It was felt that students would benefit from a Simulated Factory environment to practice the principles taught in the classroom.

Taiichi Ohno, the Toyota Manager credited with the development of the Toyota Production System, later to be coined Lean Manufacturing, stated:

> You pay money to buy books and go to seminars and gain new knowledge. But knowledge is knowledge, nothing more. Knowledge is something you buy with the money. Wisdom is something you acquire by doing but you gain the wisdom only after you have done it. The fundamental understanding of the lean operations is gained only after you have done it. No matter how many pages you may read on lean books, you know nothing if you have not done it. To understand means to be able to do. (Ohno, 2012, p. 60)

Unlike other engineering disciplines (chemical, electrical, mechanical, and computer), industrial engineers do not typically have labs to practice their newfound knowledge. The nature of Industrial and Systems Engineering requires a complete system to conduct experiments and test ideas discovered via lecture and reading. Without a Simulated Factory, Industrial Engineers are at a significant disadvantage when entering the workplace for the first time. Internships and Co-ops are beneficial, although they are unavailable to most students and do not necessarily complement the education.

In 2010, the Industrial Engineering Faculty hired a manufacturing expert to develop a Simulated Factory, teach Lean Manufacturing, incorporate lessons from the lectures, and integrate other Industrial Engineering courses into the Lego Lab. The newly appointed faculty member decided on a design involving Lego models. Lego models can simulate a complex assembly line and incorporate many Lean Manufacturing disciplines into the new system. The new Industrial and Systems Engineering Lab became known as The Lego Lab.

The continuing challenge of the Lego Lab was to incorporate key learning objectives of the Lean Manufacturing course into the environment, construct hands-on training to complement lectures and incorporate other Industrial and Systems Engineering coursework (See Figure 5).

Figure 5

Lego Lab at a Southeastern University

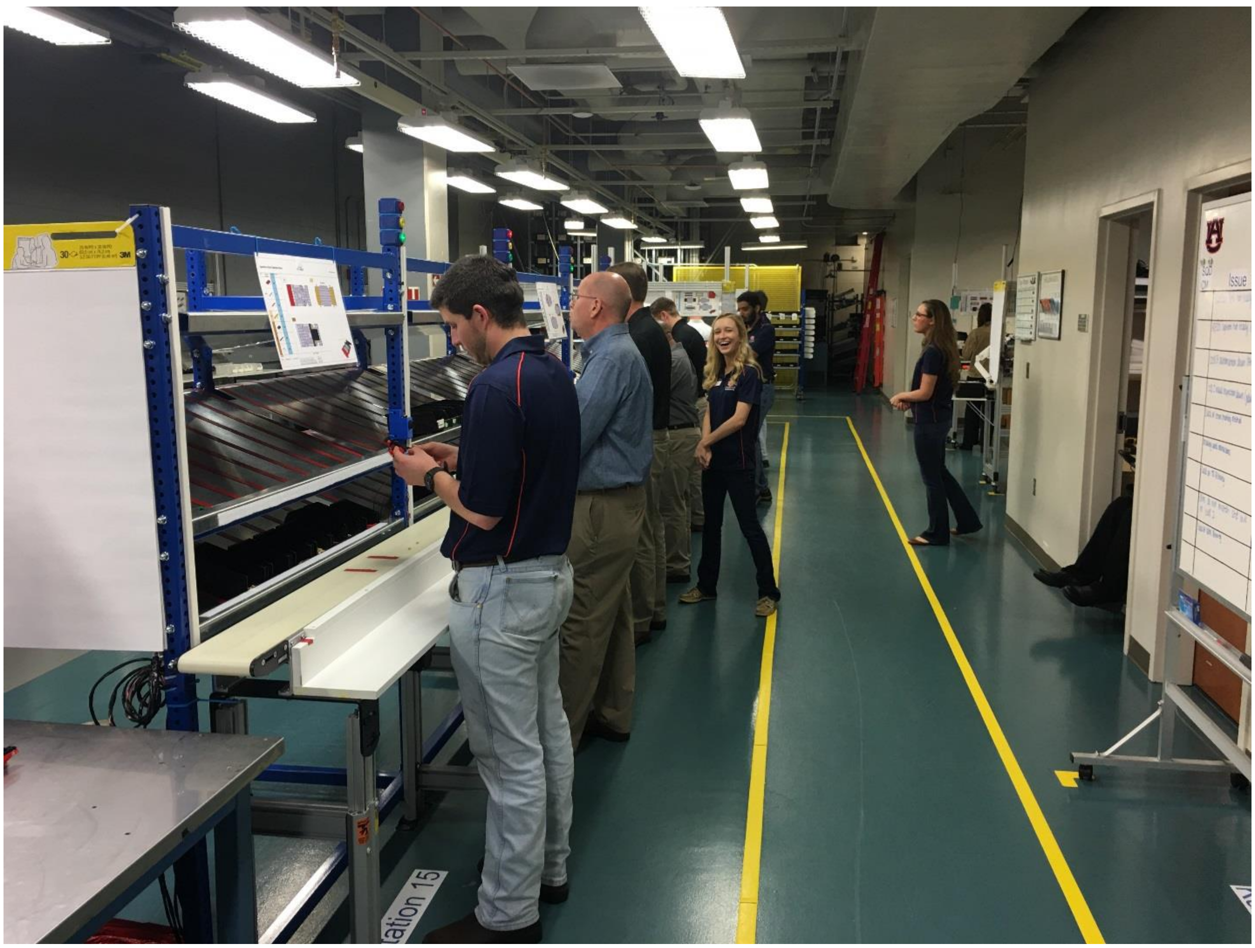
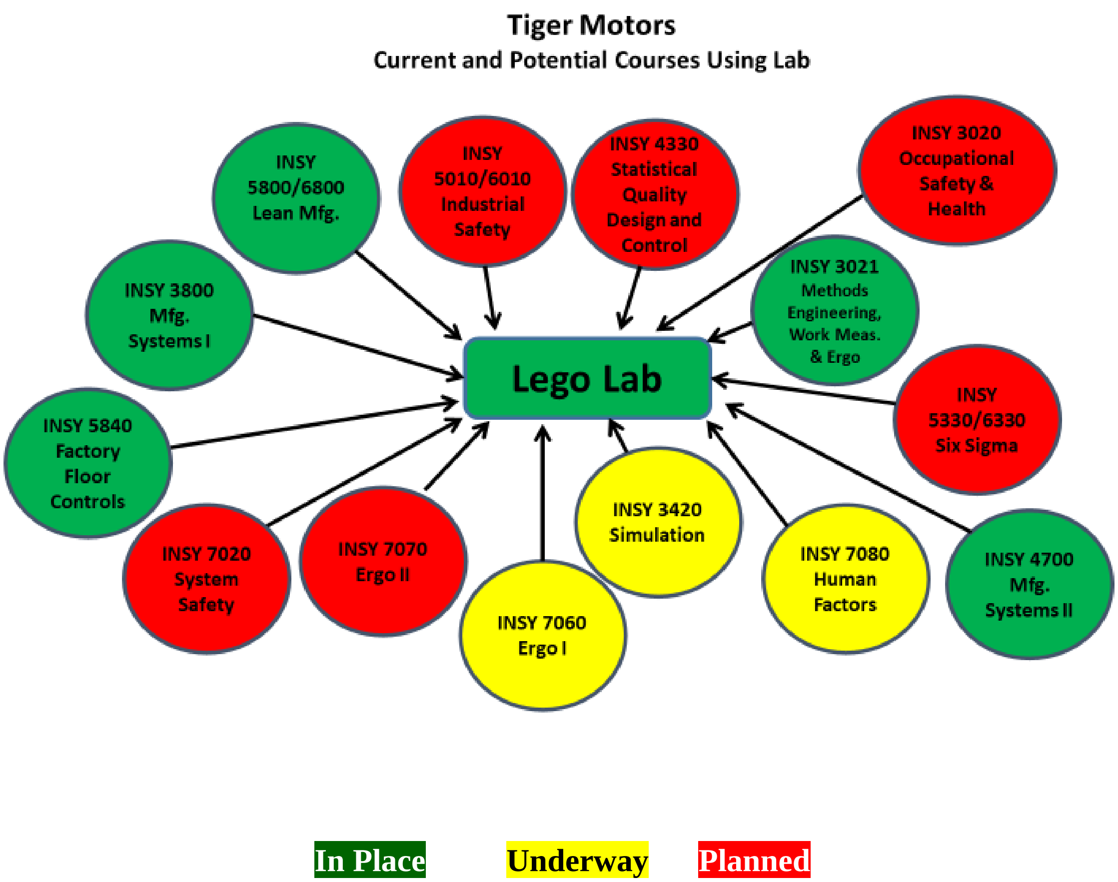


Figure 6

Industrial Engineering Curriculum incorporated into the Lego Lab



Summary

The research in Table 7 summarizes the student type, facility, experiential design, Lean Manufacturing sub-topic, and evidence of the efficacy of instruction. The last line of the table shows this research study for comparison.

Table 7

Summary of Research

Research	Participants Student (S) Industry (I)	Simulated Factory Y or N	Experiential Design Y or N	Sub-Topic Lean Focus	Evidence of Efficacy Quantitative (Q) Anecdotal (A) No Evidence (N)
Tortorella et al. (2018)	S			No	Q
De Zan et al. (2015)	I	Y	Y	No	Q
Buelhmann and Espinoza (2014)	S, I	Y	Y	No	A
Witt et al. (2018)	S	N	Y	5S	A
Harris (2016)	I	Y	Y	Waste	A
De Vin and Jacobsson (2016)	S,I	Y	Y	No	N
Van der Merwe (2017)	S	Y	Y	No	A
Kreimeier et al. (2014)	S,I	N	N	No	Q
Ahmad et al. (2018)	S	Y	Y	VSM	A
Garay-Rondero et al. (2019)	S,I	Y	Y	No	A
Current Study	**S**	**Y**	**Y**	**JIT**	**Q**

Of the eleven related research studies, only one attempted to answer a question similar to the research questions in this current study. The study by Garay-Rondero et al. (2019) statistically measured the differences between an experiential approach and traditional classroom instruction. While the data do not meet the threshold of α=.05 due to a small sample size, they indicate a trend and indicate a potentially significant difference between the two groups. The study also encouraged other researchers to test similar experiments that statistically validate the ubiquitous sense that experiential approaches are superior to traditional classroom pedagogy.

This current study differs from Garay-Rondero et al. (2019). The subject matter of this study was focused on Lean Manufacturing as a whole, with a particular interest in the Just-In-Time (JIT) sub-topic of Lean Manufacturing. As mentioned, there was anecdotal evidence that JIT subject matter is much more challenging to teach in the classroom than other Lean Manufacturing sub-topics.

An interesting point about this literature review is the lack of statistical validation of the experiential approach. While all researchers valued the experiential approach and most spent a lot of time and resources facilitating the learning environment, they do not, in most cases, attempt to validate the work and resources required to create such a valuable learning approach.

To conclude, based on the literature, there is a need for statistical validation of the experiential learning approach focused on Lean Manufacturing and the JIT sub-topic of Lean Manufacturing in a Simulated Factory. The content focus of the JIT sub-topic is of particular interest. To reinforce this approach, Womack indicated in the forward that Value Stream Mapping (VSM), a tool of JIT, is the most important step in the lean transformation and the step most often skipped in the 10-step process (Rother et al., 2003).

Many organizations, both universities and manufacturing companies, train students and employees in Lean Manufacturing principles using Experiential Learning (EL) methods. Simulated Factories (SF) have been developed by both universities and manufacturing companies to train experientially.

Of the publications highlighted in the literature review, there are no known acceptable attempts to validate experiential methods statistically vs traditional classroom lectures. This research compares students receiving classroom lectures vs students trained in a Simulated Factory (SF).

CHAPTER 3: METHODS

Introduction

Higher education uses laboratory environments to accomplish Experiential Learning based on the principles of andragogy. Andragogy is “the art and science of helping adults learn” (Knowles, 1980, p. 43). The use of labs in higher education is ubiquitous. This study’s focus is Lean Manufacturing education in a laboratory—specifically, a laboratory designed to simulate a manufacturing environment or a Simulated Factory. Participants included Lean Manufacturing Industrial and Systems Engineering students using an Experiential Learning (EL) approach. A Simulated Factory (SF), located in an engineering building at a university in the southeastern United States, designed to provide an EL environment, was used to conduct this research. Chapter 1 defines the study’s purpose, statement of problem, research questions, limitations, and definitions of terms. Chapter 2 reviews the literature on higher education institutions teaching LM in simulated factory environments. This chapter discusses research design, participants, learning environments (classroom vs lab), and data instruments.

Purpose of Study

A validated Experiential Learning (EL) approach in teaching Lean Manufacturing (LM) principles improves student knowledge. It ensures that students going to industry understand and can apply the Lean Manufacturing (LM) tools required to eliminate waste and redesign operating systems. Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165). This study also supports educators in making a case for Simulated Factories (SF) to funding agencies.

When teaching Lean Manufacturing (LM), the importance of the Just-In-Time (JIT) sub-topic is clear, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation, Rother et al, 2003). The hesitancy of managers to utilize this most important tool is an integral part of this study leading to the formulation of one of the three research questions, which focused on Just-In-Time (JIT) knowledge with 16 questions of a 47-question survey related to Just-In-Time (JIT). These 16 questions were administered to independent sample groups: students engaged in classroom lectures and experiential learning in the Simulated Factory (CLELSF) and students with classroom lectures (CL) only.

The 47 questions survey represents four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10) and JIT (16). The questions are designed to test for differences between On-Campus and Distance students. It was expected that students engaged in (CLELSF) would show improvement in all sub-topic areas of Lean Manufacturing (LM) with more significant improvement in Just-In-Time (JIT) knowledge over students with (CL).

Research Questions

The following research questions were posed in the study:

RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

RQ3: Is there a performance difference between "On-Campus" students and "Distance" students?

Distance students represented the (CL) or "No Lab" independent sample in this study, while "On-Campus" students represented (CLELSF) or students with "Lab". There may be a difference between these two groups beyond instruction. In one limited data set, On-Campus students represent the Independent Sample (CL) or "No Lab" due to the COVID isolation period in which lab activities were canceled. This data set measures the JIT sub-topic questions only.

Background

The development of the Simulated Factory began in 2010 at this southeastern university with the intuitive notion that manufacturing training requires experience. The faculty view was that students without "hands-on" experience lack capability when entering their first industrial assignment.

Methods

This study involved an experimental design with two independent variables: student survey scores involving Classroom Lecture and Experiential Learning in a Simulated Factory (CLELSF) and students with Classroom Lecture (CL) only. The dependent variable was student test scores. The test included 53 questions, as seen in Table 8. Permission was granted by Auburn University to conduct this study (see Appendix E).

Table 8

Survey Questions by Lean Manufacturing (LM) Sub-Topic Categories

Sub-Topic Category	Number of Questions
Demographics	3
JIT	11
Standardization	12
Jidoka	16
Toyota Production System (TPS)	9
Continuous Improvement (CI)	2
Total	53

Simulated Factory – Lego Lab

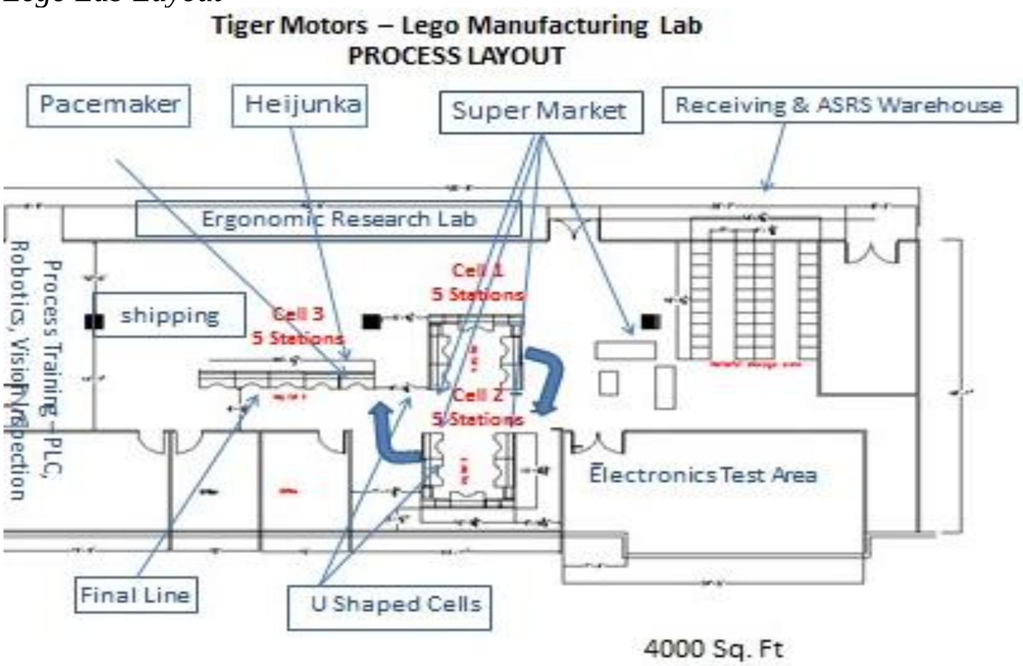
The Lego Lab (LL) at Southeastern University is a 3000 sq. ft. facility designed to simulate a manufacturing environment and teach all LM best practices. The LL comprises 15 workstations in three work groups of five stations each (two sub-assembly cells and one automated straight-line conveyor). A Just-In-Time (JIT)-sequenced supplier produces parts in a separate lab that acts as a supplier company to the LL. The supplier is configured as a Manufacturing Cell.

A Lean Manufacturing Cell refers to a specific layout arrangement in a manufacturing environment designed to optimize workflow, minimize waste, and enhance productivity by grouping all the necessary equipment, tools, and personnel required to complete a single or a series of steps in the production process. This setup facilitates a smooth flow of materials and information, enabling quick response to customer demands and reducing lead times. The goal of a Lean Manufacturing Cell is to implement lean principles, such as just-in-time production and continuous improvement, to create a more efficient and flexible production system (Lean Enterprise Institute, n.d.).

The cell consists of five Computer Numerical Control (CNC) machining centers and a 3D printer. Raw material for the LL is stored in an Auto Storage and Retrieval System (ASRS) and pulled to a Supermarket (see Figure 7).

Figure 7

Lego Lab Layout



Video link of the Lego Lab: https://www.youtube.com/watch?v=ttL1QzWc7gQ

Graduates and undergraduates from both on-campus and online courses took a 53-question pre and post-class test to measure their understanding of Lean Manufacturing (LM). The questions represent four sub-topics of Lean Manufacturing. The sub-topic areas are as follows:

- **Jidoka –** Error / Mistake Proofing in station
- **JIT** - Just-In-Time flow of material

- **Standardization –** Defined requirements for work and facility
- **TPS –** Toyota Production System – General knowledge

The Distance students did not participate in the Lego Lab (LL) experiential activities.

The sub-topic areas of Lean Manufacturing are indicated explicitly after the question number for each question in the survey. For example, Question 49 – JIT (see Appendix A). The sub-topic areas, Standardization, JIT, Jidoka, and TPS, are incorporated into the Lego Lab. Students work within this environment during the semester and are divided into three teams, one for each manufacturing cell (cells 1, 2, and 3). Teams include five undergraduates and one graduate Team Leader. Teams participate in three production runs scheduled throughout the semester. The production runs follow a sequence of improvements from Mass Production to Lean Manufacturing Systems Design to Continuous Improvement. The Mass Production run represents the Henry Ford model popularized by the Model T. The second production run represents LM, which Toyota popularized. The final production run, Continuous Improvement, incorporates improvements made by student teams.

Students are tasked with achieving an Overall Equipment Effectiveness (OEE) score of 75% by the final production run. OEE is a function of Quality, Performance, and Availability (QxPxA). In addition to the production runs, students engage in experiential learning of critical systems / sub-topics of LM. The combination of specific training and the production runs intends to expose students to a rich learning environment that complements the classroom lecture.

Before the Continuous Improvement production run, graduate students produce an A3. see Appendix B, problem-solving document. The A3 shows the gap between actual Overall Equipment Effectiveness (OEE) performance and the goal. A fishbone, or Ishikawa Diagram, see Appendix C, is used to identify potential failure modes, followed by a Five Why analysis, see

Appendix D, to confirm the root cause. Once the root cause is determined, plans are developed to address the root cause. OEE performance in the final production run should meet the 75% OEE objective if done well. The graduate students work with their designated undergraduate team to brainstorm potential problems, confirm root causes, and develop action plans in the A3 document.

The formula for Overall Equipment Effectiveness is OEE = P x Q x A where P=Performance, Q=Quality, and A=Availability. If Performance is 90%, Quality is 80%, and Availability is 95%, OEE ==.9 x .8 x .95 or 68.4%. The following description provides more detail about the significance of overall equipment effectiveness (OEE) as it is equal to the multiplication of the three main bases for the main six big losses: "1. Availability indicates the problem that caused downtime losses; 2. Performance indicates the losses caused by speed losses and; 3. Quality indicates the scrap and rework losses" (Almeanazel, 2010, p. 519).

Figures 8, 9, and 10 represent the student scorecard for the three production runs (Mass, Lean, Kaizen). Figures 11 and 12 show OEE and the overall scorecard for each student lab team.

Standardization

Standardization defines how products are processed via work instruction at the job station and creates the blueprint for the physical facility. Five S. Standardization acts as the foundation for control and experimentation for continuous improvement. Taiichi Ohno, the Toyota executive credited with developing the Toyota Production System or Lean Manufacturing, famously said, "Where there is no standard, there can be no kaizen." Kaizen is the Japanese term for Continuous Improvement.

Figure 8

Quality Represents the Percentage of Acceptable Product of Total Possible

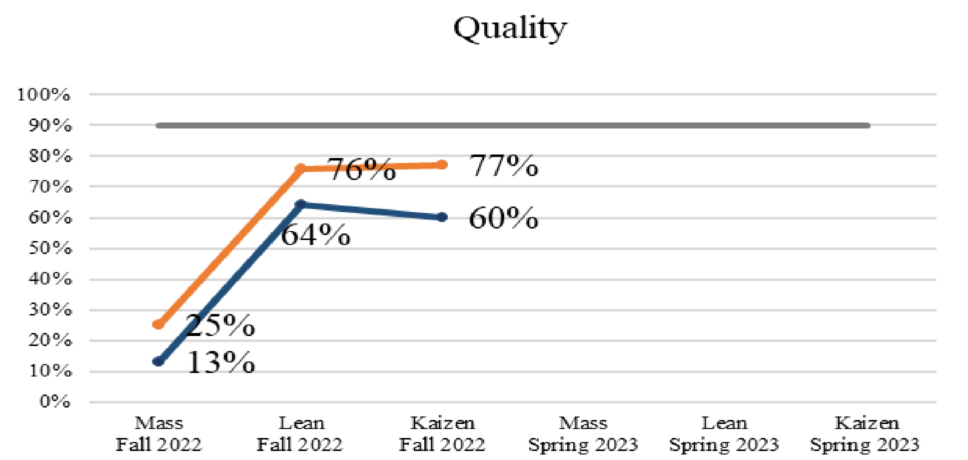


Figure 9

Performance Represents the Percentage of Product Produced of Total Possible

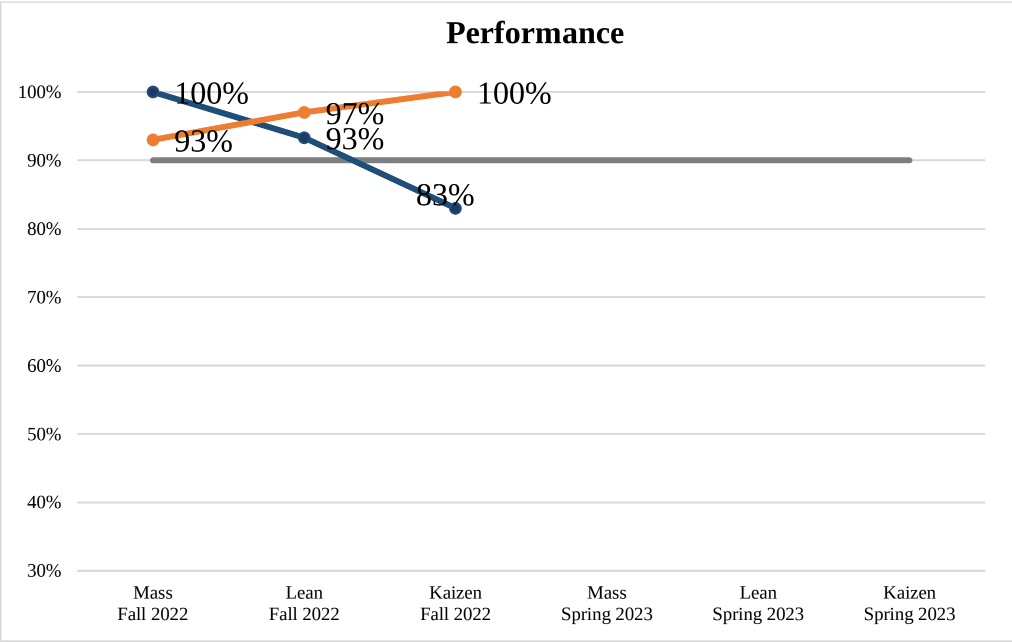


Figure 10

Availability Represents Percent of Run Time of Total Possible Run Time

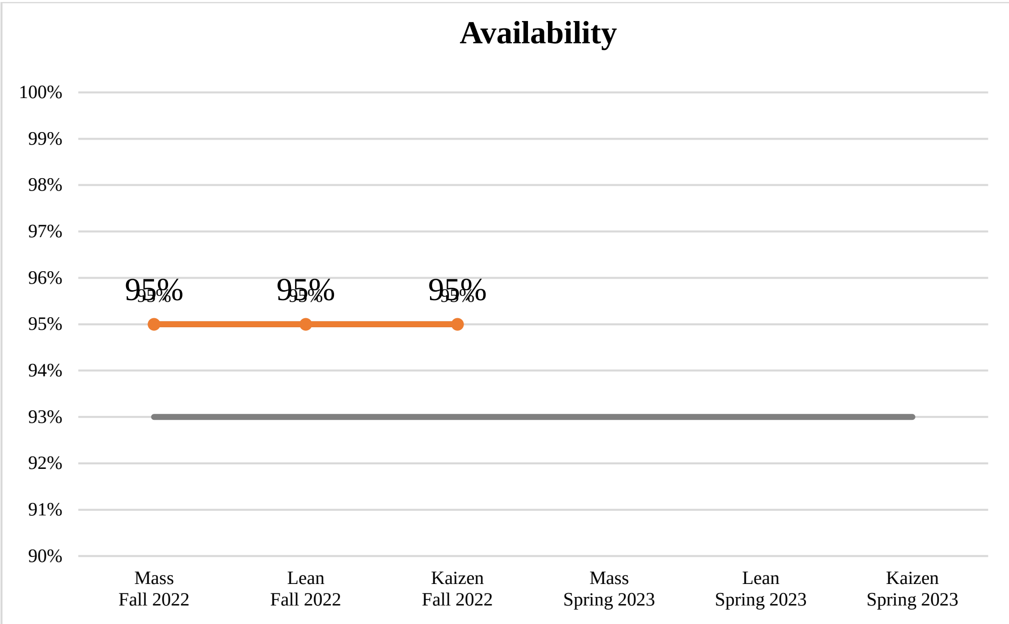


Figure 11

OEE is a Function of Quality X Performance X Availability

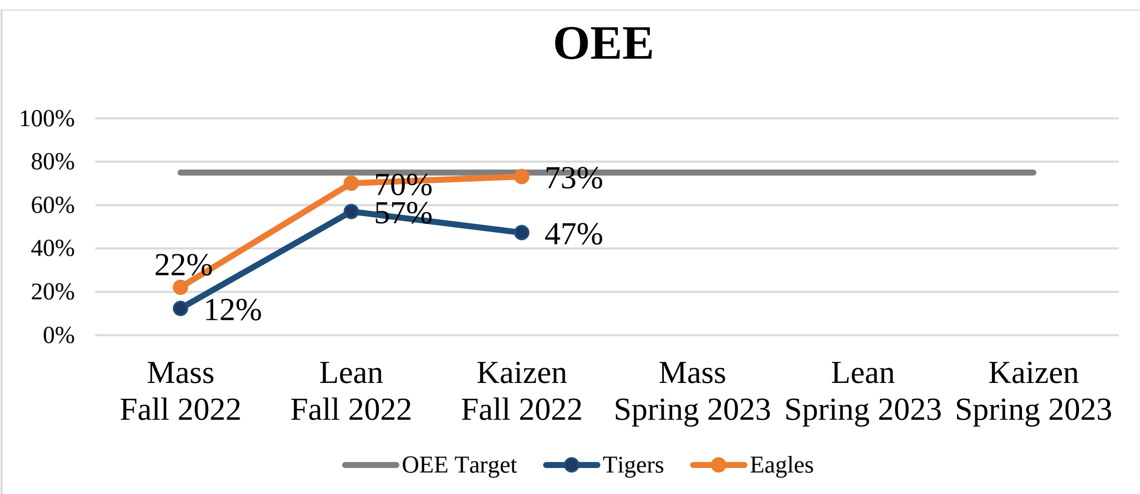
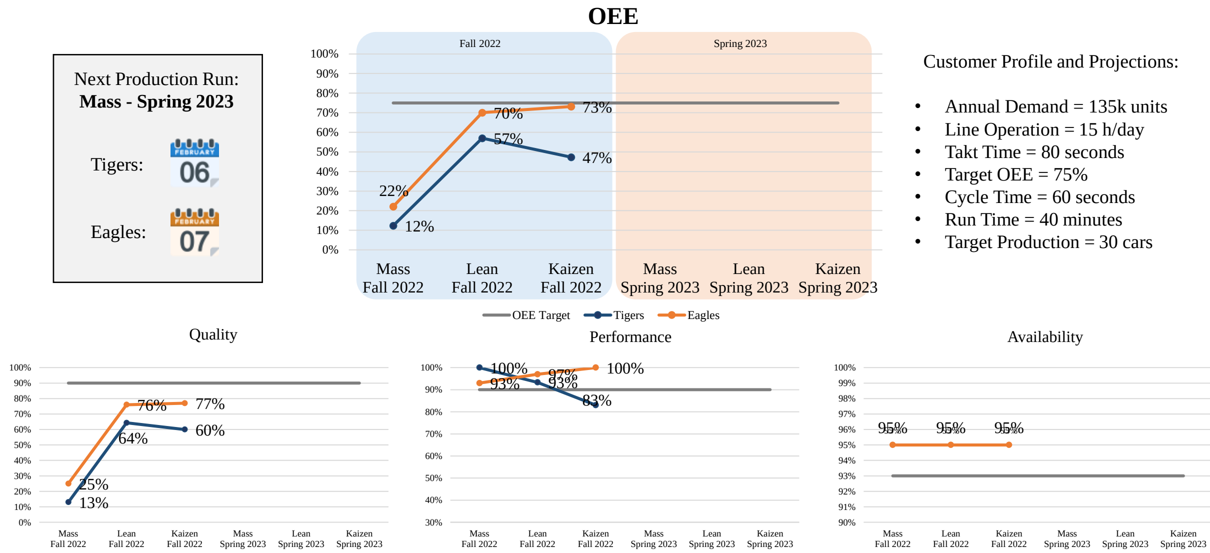


Figure 12

Scorecard for Each Lab Team



Information covering Standardization is presented in the classroom and reinforced experientially. Two exercises cover standardization, 5S, and Standard Work Instructions.

5S

5S is a method of standardizing the physical facility to create a visual factory. Once defined, managers can spot deviations from the standard quickly. This system helps managers ask the right questions and assure conformance and control. The 5S's follow the sequence: Sort, Set In Order, Standardize, Shine, and Sustain. Sort requires all items within the workplace to be tagged red for removal, yellow for items used periodically (not each machine cycle), and green for all necessary items within the workstation for every cycle. Set In Order defines a place for everything and everything in a designated identified space. Footprinting, shadow-boarding, and labeling define the location and create a visual cue when items violate the standard. Standardize defines workplace rules, Shine requires all areas and equipment to be cleaned, and Sustain requires a system to ensure the first four Ss remain in control. 5S also includes Key Performance Indicators (KPIs), Problem-Solving Boards, and other operational standards and methods of operation.

5S is presented in the classroom and reinforced in the lab in the following manner: The Lego Lab 5S system is well-developed. Work Instructions are posted in all fifteen workstations. Tools and other equipment are footprinted and shadow-boarded. KPIs are posted with Actual vs. Target. Problem Solving Boards are displayed with items identified by status (Yellow – In Process, Green – Complete, and Red – Past due). The activity within the lab involves creating abnormalities by moving items out of their defined space, displaying KPI's missing target, and presenting past-due initiatives on the problem-solving board.

Some items have no designated location defined. Students tour the lab and document abnormalities. The student teams then report their findings to the group. After the review, all created abnormalities are shared with the teams. The exercise aims to demonstrate how the standardized facility creates a visual management system highlighting deviation from standards. This methodology helps managers and teams respond rapidly to out-of-standard conditions and maintains workplace organization.

5S Deviation Walk-Through

The students will be challenged to pick out places in the Lego Lab that represent "Deviation in the Workplace" according to the 5S Standards. Each student will be given a document (see Figure 13). Twenty minutes will be allotted for the class to walk through and observe the lab to identify deviations.

Deliverables

The 5S Deviation Activity Sheet was submitted in the lab. Students used the Activity Sheet (see Figure 13).

Figure 13

5S Document Used by Students to Identify Non-Conformances in the Lego Lab

Identify 5S deviations in the Tiger Motors lab. Record below.

Sort	Straighten	Shine	Standardize	Sustain	Location	Violation Description

Figure 14

Example of Completed 5S Lego Lab Evaluation of Non-Conformance

Deviation	Time	Type
Red card on 5S Board	0:39-0:47	Deviation of System
5S Graph on edge of 5S board	1:13	Deviation of System
Not meeting target, chart below 5S Station graph	1:22	Deviation of System
Mop bucket in front of eye wash	0:20	Set in Order
Trash Can out of position	0:10	Standardize
OEE Graphs all not meeting targets (Quality and Performance and OEE)	1:56	Deviation of System
Cart not in place	1:50, 2:11, 8:46	Deviation of system
Continuous Improvement Board - red item	2:20	Deviation of System
Shadow tool board missing tools	8:36	Deviation of System
Tall Ladder against the wall not labeled	10:44	Standardize
Old Robot on pallet, mess of parts	11:01	Sort
Bus escape door, doesn't belong	11:15	Sort
Recycle can by back door	11:19	Deviation of System
Green and orange LEGO disassembly tools on workstations (multiple places) don't have a proper place	3:29, 3:38,8:04	Set in order
Instructions missing in cell 1, station 5	7:38	Deviation of System
Stations have more than one part on the top	4:26, 4:51,5:40	Deviation in system
Dry wipes hanging out of wipe container by back door	11:19	Sanitize
Sink is very dirty	11:46	Sanitize
Bins behind stations should all be empty	9:53	Sort
See evidence of Sustainment System, the 5 S Board.	0:39	Sustainment
No sustainment system for Robot area	1:33	Sustainment
No sustainment system for ASRS system in back of lab	10:10-10:35	Sustainment

Standard Work

The Pig exercise has been used in many organizations to illustrate the power of clear work instructions. In step one, students are given detailed instructions and a grid to draw the pig. If not followed precisely, the result is not what the customer expects. When students display their drawings, variation clearly shows that no one drawing looks like another. Variation leads to dissatisfied customers.

In step two, more clarity is provided. Even when variation is reduced, no two pigs look alike. Finally, in step three, the students are given a picture of the pig laid over the grid. It is straightforward to draw from box to box, thus significantly reducing variation.

This exercise demonstrates the need to emphasize work instructions in manufacturing operations and involve employees in their development. Public Health Ontario health promotion consultant Allison Meserve used the version in Figure 15. Allison adapted this exercise for use at a workshop for managers at Chatham Kent Public Health 2016.

Figure 15

Pig Exercise Used in the Lego Lab to Illustrate the Negative Quality Impact of Poorly Written Work Instruction

Standard Work Instructions: – The "Pig" Exercise

The purpose of this activity is to help the students understand the importance of standard work.

LEARNING OBJECTIVES

Following the exercise, participants will be able to discuss the benefits of using a written program description or logic model at the outset of evaluation.

NOTES FOR FACILITATORS

Time for exercise: 20-30 minutes, depending on the depth of the conversation.

Materials needed:

• Instruction sheets

• Standard pig exercise grid

• Markers/pens for all participants

• Additional raft supplies for decoration (if desired)

FACILITATION INSTRUCTIONS

1. Provide each participant with one of the standard pig exercise grids and at least one marker/pen.

2. Introduce the exercise by introducing the concept of standard work. Explain that this exercise will introduce this concept more fully.

3. Pass out Instruction sheet 1 or copy and paste the instructions onto a slide. Tell participants that they will have two minutes to complete the first set of instructions on the standard pig exercise grid.

4. Following the two minutes, ask participants to hold up their pigs so everyone can see. Facilitate a discussion on what participants' experience was like and what they notice about the different pigs. Ask participants to keep this sheet.

5. Pass each participant a second standard pig exercise grid and Instruction sheet 2. Tell participants they will have three minutes to complete the instructions on the grid.

6. Following the three minutes, ask participants to hold up their pigs so everyone can see. Facilitate a discussion on what drawing a pig was like this time compared to the first time and

what they notice about the different pigs.
7. Pass each participant a third standard pig exercise grid and Instruction sheet 3. Tell participants they will have two minutes to complete the instructions on the grid. They can use both Instruction sheet 2 and 3 for this exercise.
8. Following the two minutes, ask participants to hold up their pigs so everyone can see. Facilitate a discussion on what drawing a pig was like this time compared to the first two times and what they notice about the different pigs.

Standard Work Instruction: – Lab Processes

The following two figures represent the actual work instructions for a Lego Speedster and SUV, the two models built in the Lego Lab. While there are 15 work instructions for both models, from station 1 to 15, the two represent the work in station 15, the last station of the build for both vehicles.

The part content for the Speedster and SUV is 277 and 234, respectively. Based on problems identified throughout the semester, students were challenged to understand the method of building and modifying as needed (See Figures 16 and 17).

Just-In-Time (JIT):

Just-In-Time is one of the four sub-topic areas of the survey instrument. There are several lab activities designed to reinforce JIT understanding. "The Kanban system is an information system that harmoniously controls the production of the necessary products in the necessary quantities at the necessary time in every factory process and among companies. This is known as Just-in-time (JIT) production" (Monden, 1993, p. 15).

Figure 16

SUV Work Instruction in Station 15

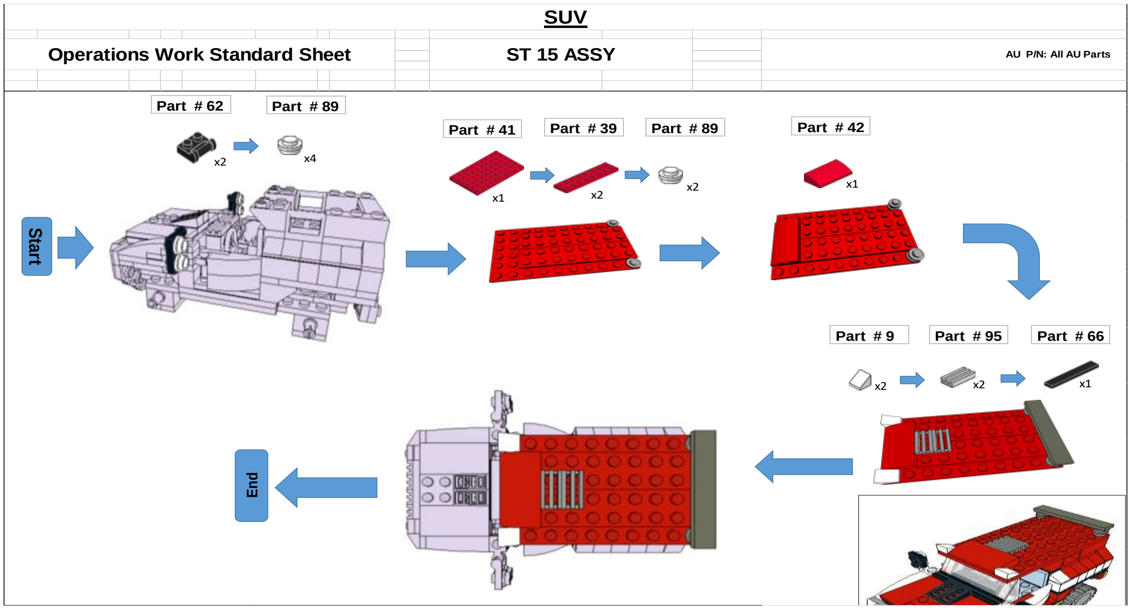
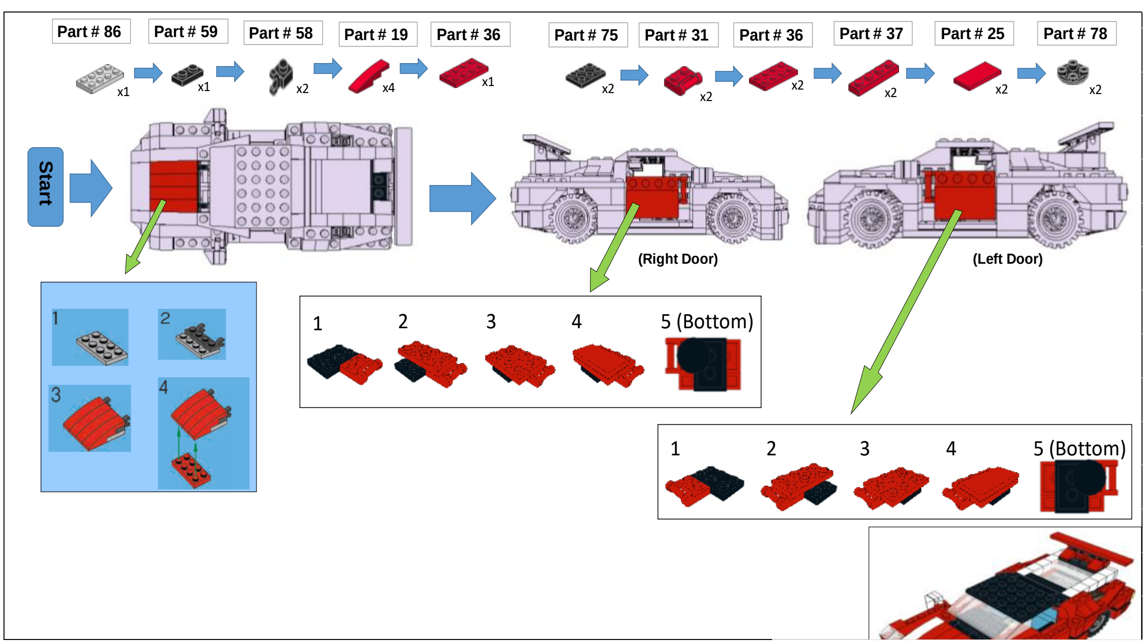


Figure 17

Speedster Work Instruction in Station 15



Just-In-Time (JIT) material flow architecture is designed to produce only when the customer signals, the customer being both the final customer of the finished product and internal processes producing sub-assemblies for the following process downstream. Traditional mass production methods project the demand and product mix using software systems. The approach, known as Material Requirements Planning (MRP), generates a schedule for each area of the plant with the intent of efficiently forecasting to ensure products are available without unnecessary delays (Heizer et al., B. (2021).

Just-In-Time (JIT) provides perfect knowledge of what to produce because each area/process is connected and replaces the sub-assembly or final product that the customer withdrew vs. producing a calculated projection without regard to what was withdrawn by the customer. When the inevitable MRP-related variation to the planned schedule occurs due to changed orders, scrap material, missed performance projections, down equipment systems, and incorrect forecasting caused by incorrect inputs, processes produce unnecessary parts not needed by the customer. This leads to shortages, excess inventory, expedited shipments, and ultimately to planned increases in Work-in-process (WIP) Inventory levels, thus increasing Lead Time to the customer. Mass production organizations respond by adding safety stock and finished goods to prevent shortages. Added WIP and Finished Goods inventory further increase Lead Time, causing longer delays from order to delivery. New orders must ideally flow First In, First Out (FIFO) through excess inventory and finished goods. Just-In-Time strategy is a feature of Lean Manufacturing that differs from traditional mass production.

As discussed in the introduction, the LM sub-topic of JIT is particularly difficult to comprehend in a lecture environment. Taiichi Ohno sent senior managers to supplier locations to teach JIT. Past teaching attempts failed, and Ohno concluded JIT must be taught while implementing JIT at supplier locations. Jim Womack, the author of Lean Thinking, identified Value Stream Mapping (VSM) as the step most often skipped in the five-step process of Lean transformation in the forward of Learning to See (Rother & Shook, 2003). VSM is a JIT tool used to uncover waste within a manufacturing system. Trainees understand the importance of VSM on an intellectual level. However, implementation requires experience for the deep understanding needed for use. Given the critical need to understand JIT, several lab activities center around this lean strategy.

Value Stream Mapping

Value stream mapping is a tool that allows visualization of the flow of material and information. The tool highlights waste or non-value-added activity in a manufacturing system, targeting the waste for removal (Rother & Shook, 2003).

Lead Time is the primary metric determined from Value Stream Mapping (VSM). Lead Time is a function of inventory and takt time (Inventory) x (Takt Time). Takt Time is calculated as the rate at which the customer pulls product from the facility. For example, if a customer pulls product at the rate of one unit every 60 seconds and the inventory count equals 5,000 units, Lead Time = 5,000 x 60 seconds or 5,000 minutes. If the product is produced First In, First Out (FIFO), it will take 5000 minutes from order to delivery. The organization's primary goal is to reduce inventory to become more customer-responsive. Flexibility in the process is necessary to accomplish inventory reduction. Four lean system methods displayed in the LL are Single Minute Exchange of Die (SMED), Supermarkets, Heijunka, and Kanban.

Single Minute Exchange of Die (SMED) is an essential strategy used to implement JIT (Just-In-Time) in manufacturing systems. SMED is a lean manufacturing process developed by Shigeo Shingo to reduce the time required to complete equipment changeovers dramatically.

Single minute refers to reducing changeover time to under 10 minutes. SMED improves flexibility in manufacturing, allowing for rapid change from one product type to another, which reduces inventory and, therefore, lead time from order to delivery (Shingo, 1985).

When changeover times are long, a company building two product types on the same line must build in batches to be efficient. For example, if the changeover time equals five minutes and the processing time is 60 seconds, the company cannot mimic the customer mix: 2 of product A and 3 of product B. To follow the customer buying pattern, five cycles would require a changeover of 5 minutes every two cycles or 7 minutes to produce 2 minutes of product. The company must, therefore, batch-build to be competitive. SMED is a process of methodically evaluating changeover elements to reduce time to a level that allows the process to mimic the customer's buying pattern. Excess inventory due to batching for a mass producer does not violate their Mass Production Plan.

The Lego Lab has a Single Minute Exchange of Die problem that must be solved to allow building the customer product mix requirement. The changeover takes five minutes. The team builds one product for 20 minutes, then changes the die for the following product for the remaining 20 minutes. The second production run, or Lean Production run, introduces JIT architecture for material flow, thus requiring student teams to build to the demand and mix of the customer. The SMED project improved the changeover from 5 minutes to 3 seconds, allowing students to build the mix required without batching—the SMED improvement significantly reduced WIP inventory and lead time. Students experience how SMED allows flexibility and reduces inventory and Lead Time.

The ultimate goal of JIT is to produce one piece at a time between each process. One-piece flow of material represents the perfection of the material delivery system. It is an ideal goal of a lean organization, however it is rarely realized and acts as an ultimate target to measure the improvement of the organization. Where one-piece flow cannot be accomplished, supermarkets are installed to ensure the pull from the customer is intact. The supermarket becomes the customer of the upstream process. As the customer withdraws parts from the supermarket, a kanban signal is sent to the upstream process to replenish the supermarket based on what was withdrawn. Hence, the material pull is intact. A just-in-time supermarket is a buffer of various parts sized and designed to support the pull of material where one-piece flow cannot be accomplished (Monden, 1998).

Heijunka is a scheduling system that controls volume and product mix to represent customer buying patterns. This leads to system flexibility, reduced waste, and improved efficiency. Heijunka reduces batching, reducing Work-in-Process Inventory and Lead Time from order to delivery (Liker, 2004).

Kanban sets the system up for material to flow from customer "Pull" vs. "Push." Traditional Mass Production uses the Push method. Taiichi Ohno visited Henry Ford's Mass Production system to benchmark practices. He returned from the U.S. with the idea of Pull production that was inspired while visiting an American supermarket. The idea of the customer taking whatever was needed from the shelf, followed by a replenishment back to the farm, made clear to Ohno a system that would allow Toyota to compete in the automotive sector. Supermarkets were forced by necessity to develop a pull system since many foods cannot be warehoused due to spoilage.

Toyota's situation, requiring a high mix of products at low volume, could only compete using the pull method found in the food processing industry. Toyota did not have adequate capital after the war. Their customer demanded various products, and the volumes were minimal compared to Western manufacturers. Toyota’s situation would not allow Henry Ford's view that “the customer can have any color they like, as long as it is black.” Ford's mass production system was built on efficiency, gained by not introducing manufacturing complexity. JIT could only be accomplished by building only what the customer wants when they want it. This approach defines the Toyota Production System (TPS) or Lean Manufacturing, a term coined in the landmark publication “The Machine That Changed the World.” JIT is the system architecture for material Pull vs Push and is designed into the LL.

Components of a Pull System incorporated into the Lego Lab include Heijunka, Kanban, Supermarkets, Two-Bin Replenishment, and SMED (See Figures 18-30).

Figure 18

Heijunka Box Represents the Customer Buying Pattern, Both Mix and Volume

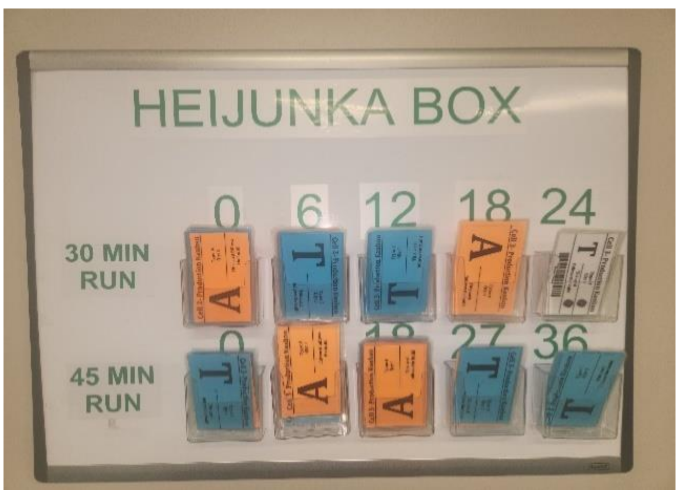


Figure 19

Kanban Post Station 11. Station 11 Paces the operations from the Heijunka and is Considered the Pacemaker Process

Figure 20

Supermarket at Station 6

Figure 21

Kanban Withdraw from Station 10

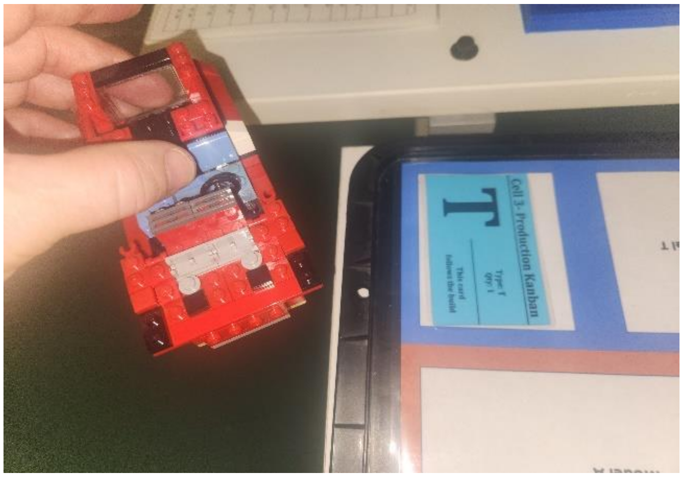


Figure 22

Kanban Post Station 6

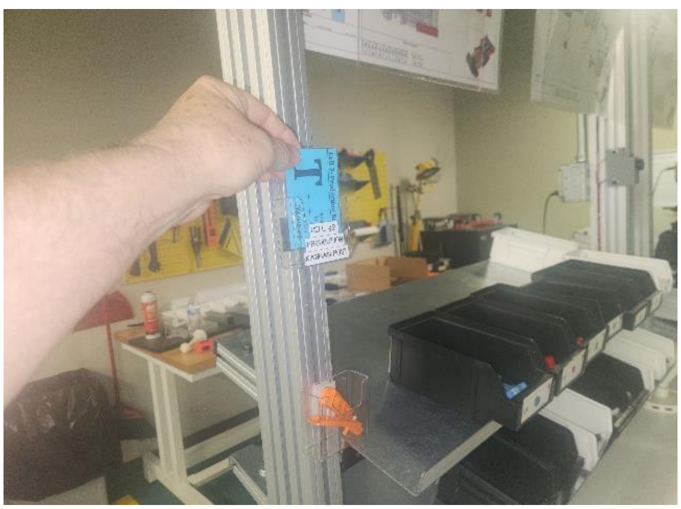


Figure 23

Kanban Withdraw, Station 6

Figure 24

Kanban Post Station 1

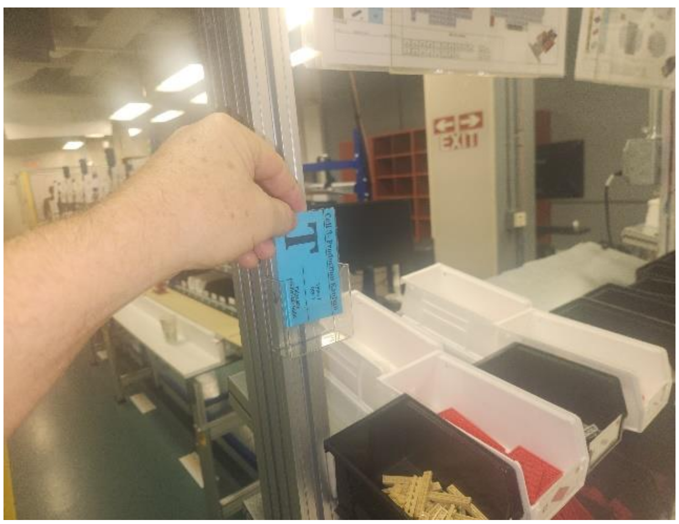


Figure 25

Two Bin Replenishment – Raw Material Pull

Figure 26

Inventory Location Instruction – Two-Bin System – Raw Material

Figure 27

Inventory System – Raw Material

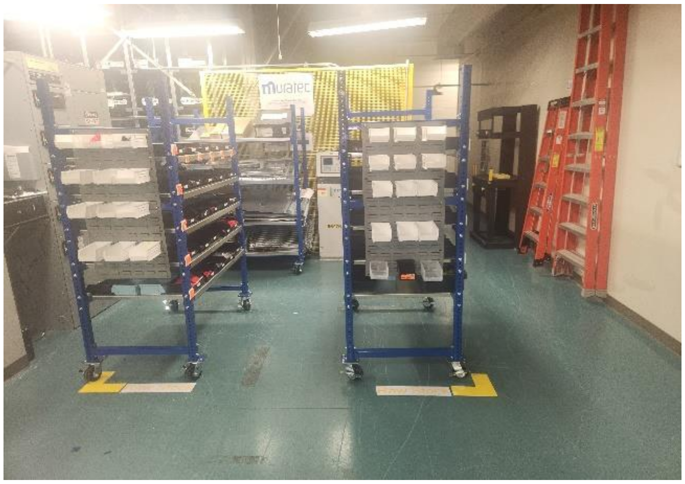


Figure 28

Two-Bin Replenishment – Raw Material Carts

Figure 29

Auto Storage and Retrieval System (ASRS) – Represents Tier 1 Supplier Delivery

Figure 30

Single Minute Exchange of Die (SMED) – Station 5

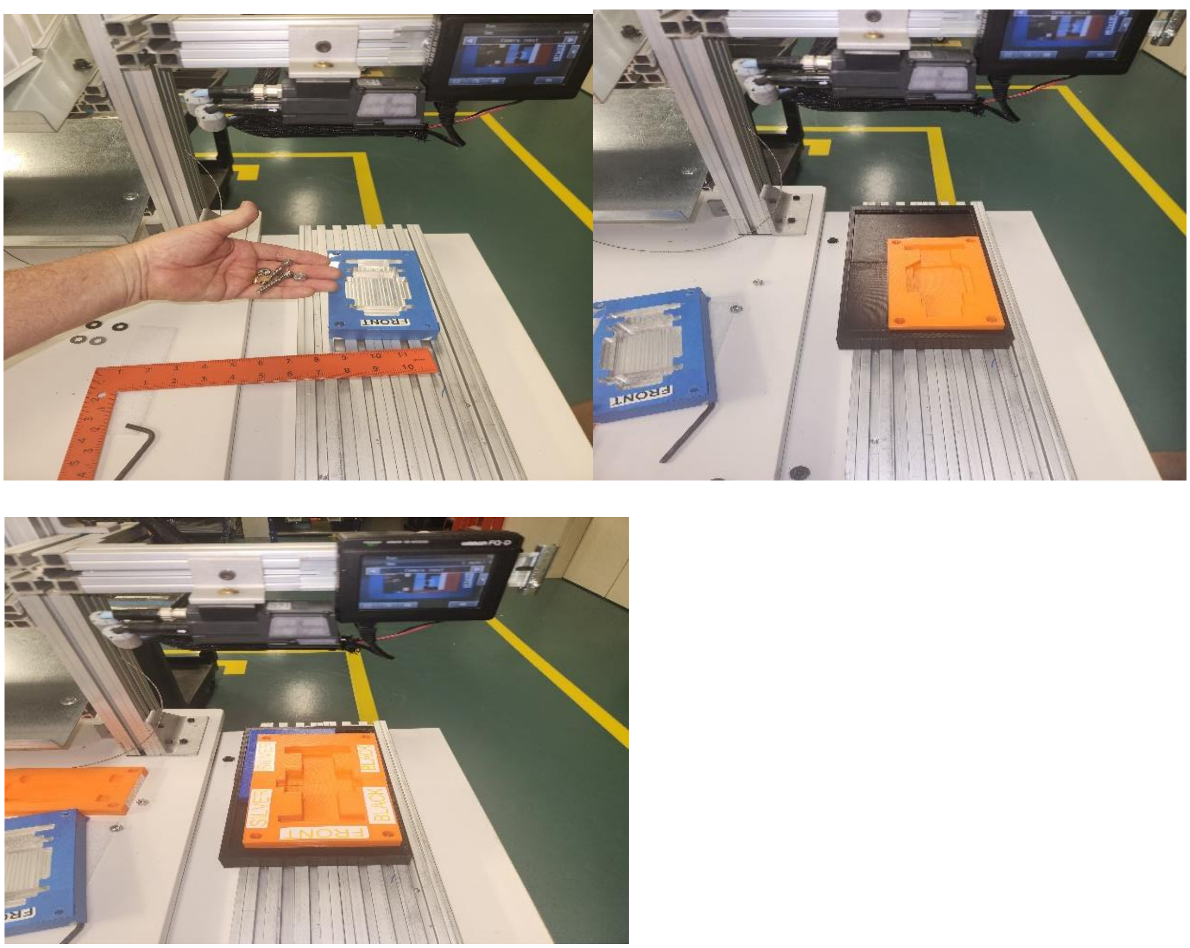


Figure 31

Current state Value Stream Map of the Lego Lab, Stations 1 – 5. Lead Time = 5700 seconds.

Processing Time = 300 seconds.

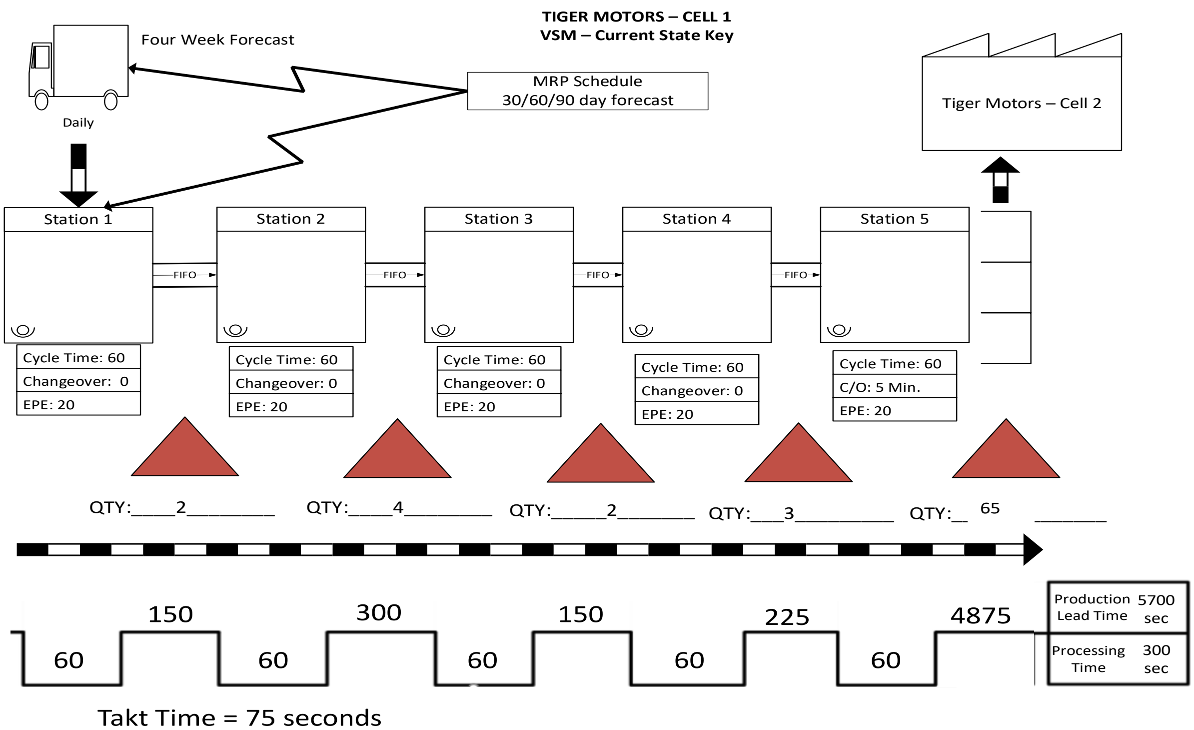


Figure 32

Current state Value Stream Map of the Lego Lab, Stations 6 – 10. Lead Time = 1875 seconds. Processing Time = 300 seconds.

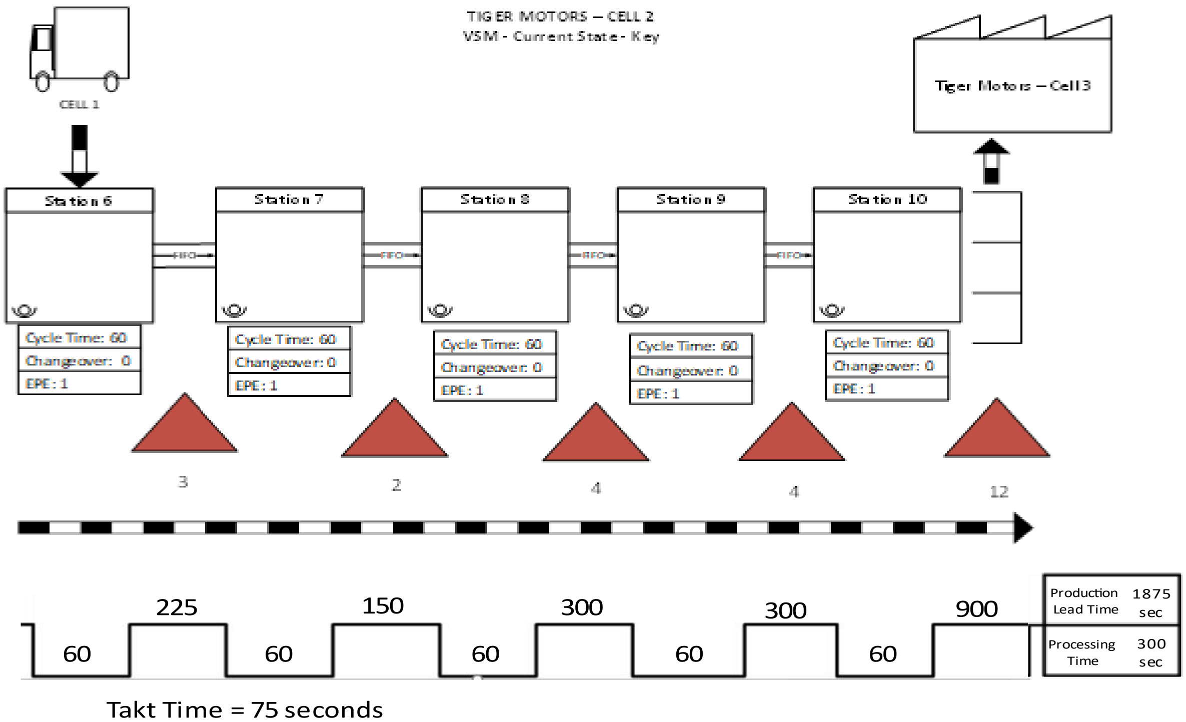
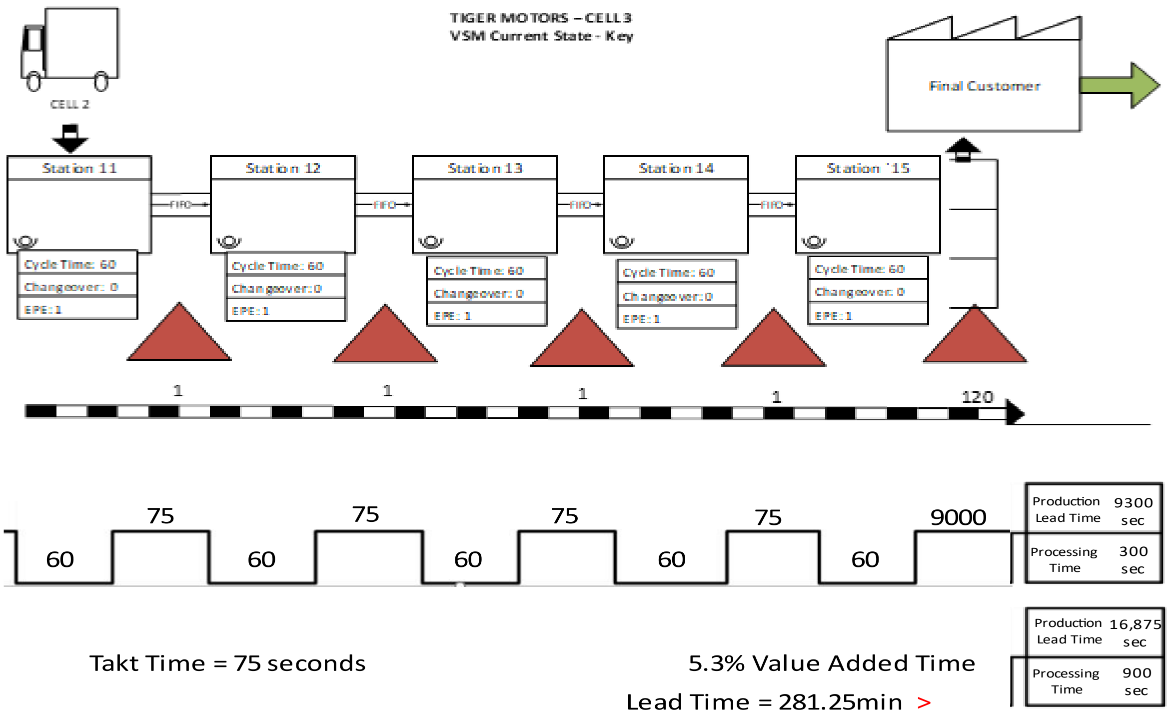


Figure 33

Current state Value Stream Map of the Lego Lab, Stations 11 – 15. Lead Time = 9300 seconds. Processing Time = 300 seconds. Total for 15 Stations, Lead Time 16,875 Seconds, Processing Time 900 Seconds.



After students calculated the Lead Time of the current system by drawing the Current State VSM, they understood what drives Lead Time. Changes to the manufacturing system were added during the Lean Production Run. A single-minute exchange of die (SMED) project, Heijunka and Kanban, a single-piece Flow, and calculated supermarkets were implemented. The Future State VSM was created, which shows a significant improvement in Lead Time. The Push system of material flow was converted to a Pull system of material flow. Because of the reduced Lead Time, the Finished Goods Inventory could be eliminated because the new lead time was shorter than the delivery promised to the customer. The system can now respond to an order with a Lead Time that meets customer expectations. Note that the processing time at the bottom of the map is much faster than the lead time.

Figure 34

Future State Value Stream Map and answer key for the lab exercise. Lead Time of Stations 1-5, 3750 Seconds, Processing Time 300 Seconds

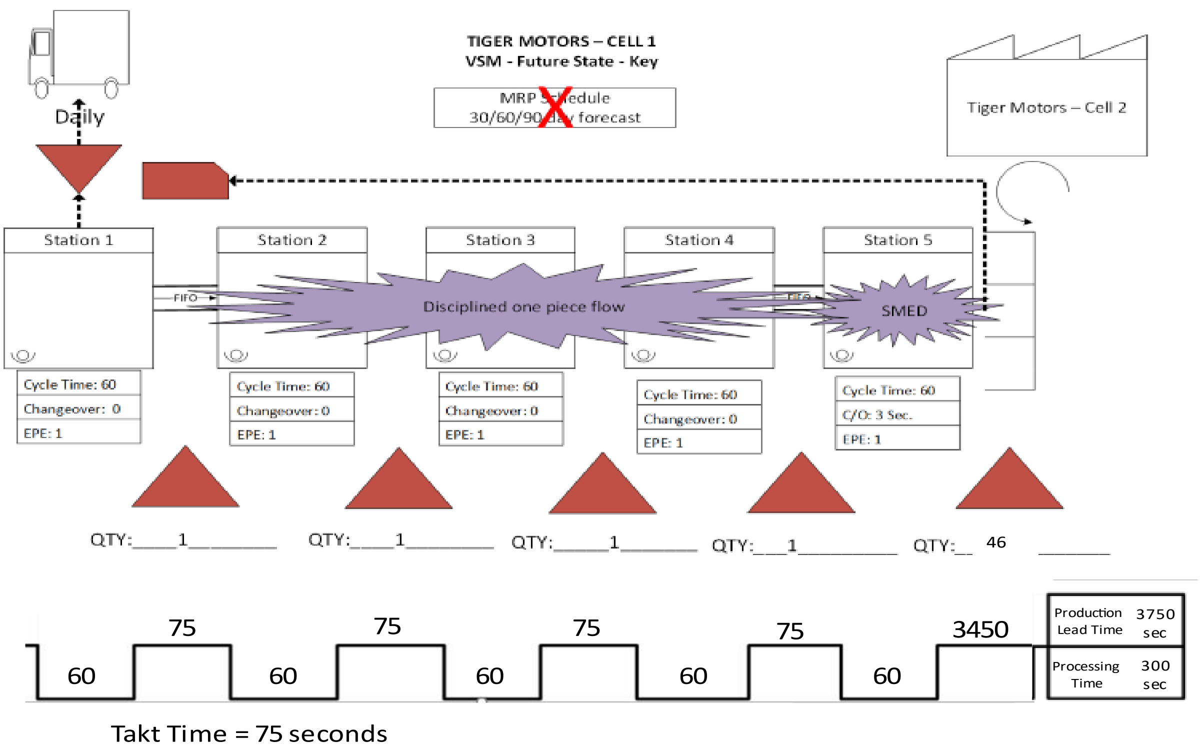


Figure 35

Future State Value Stream Map and answer key for the lab exercise. Lead Time of Stations 6-10, 375 Seconds, Processing Time 300 Seconds

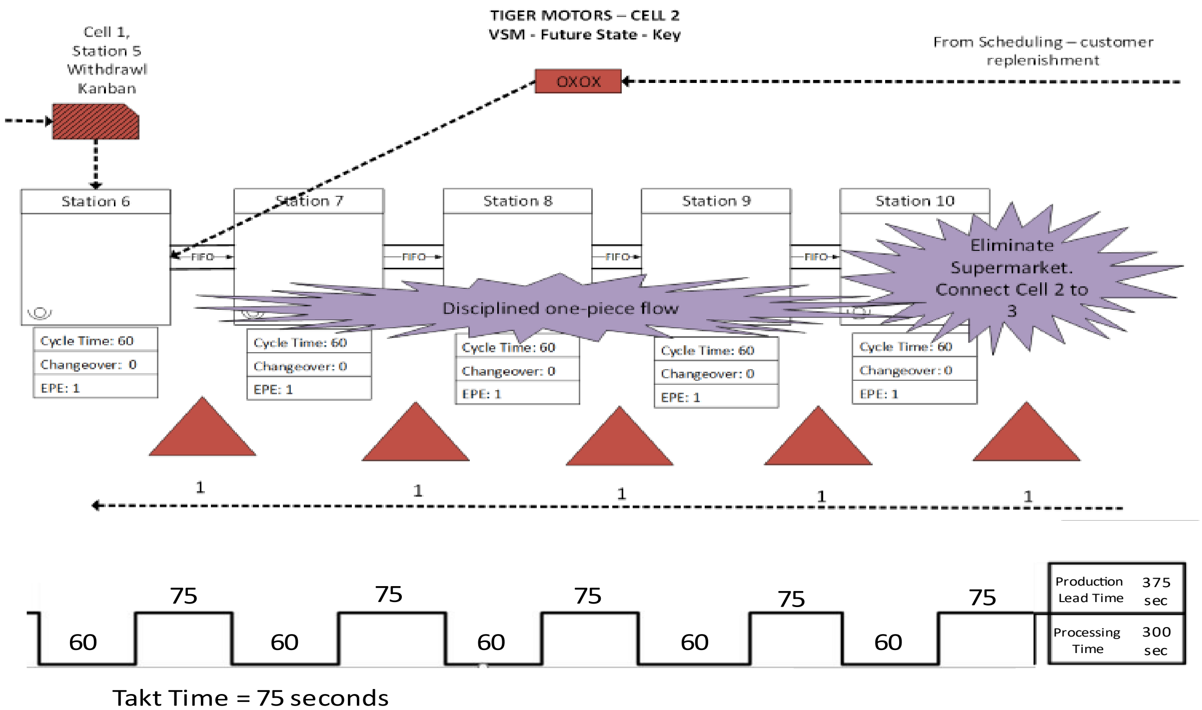
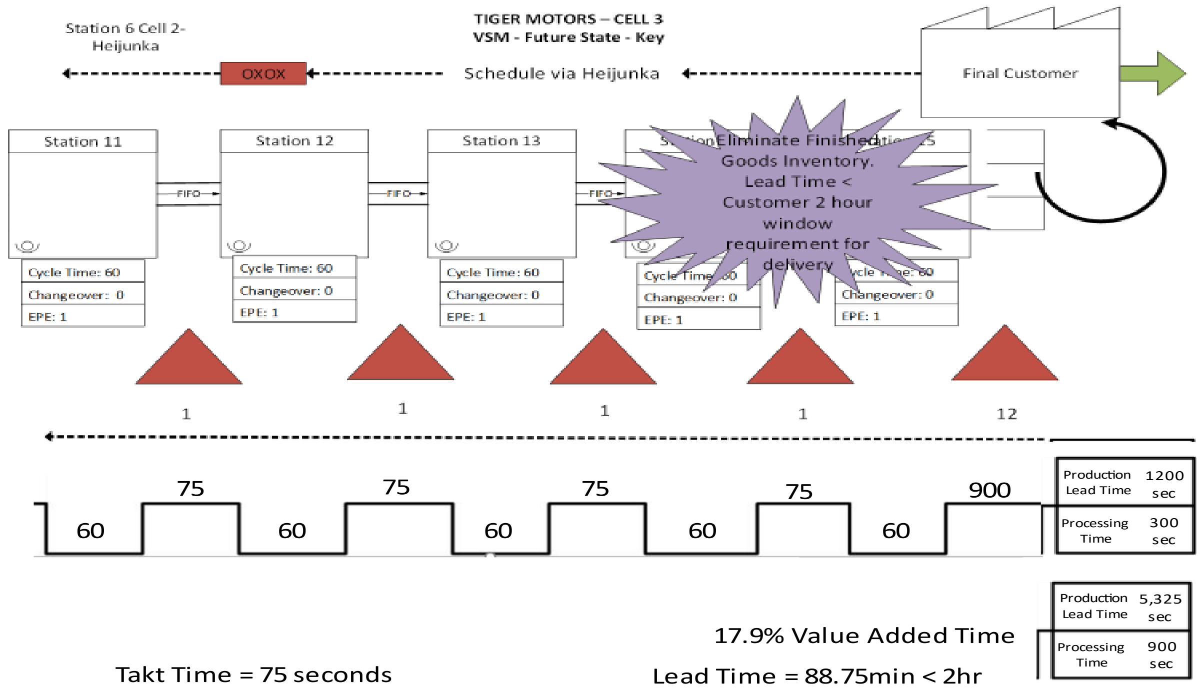


Figure 36

Future State Value Stream Map and answer key for the lab exercise. Lead Time of Stations 11-15, 1200 Seconds, Processing Time 300 Seconds. Total for 15 Statoins: Lead Time 5325 Seconds, Processing Tiem 900 Seconds



The Value Stream Mapping method of evaluating a system's customer responsiveness allows students to engage with the system physically, understand the reasons for excessive inventory, and implement improvements in an Experiential Learning environment. Classroom lectures alone cannot provide the richness of this approach.

Jidoka

The concept of Jidoka requires process methods that prevent defects from exiting the work-station of origin. “This mechanism stops the line (or machine, etc.) when there is a problem, inducing people to take action. If the line never stops at all, that may be considered wasteful since problems remain hidden" (Suzaki, 1993, p. 165). The concern when no problems are found in the work-station is that the process does not detect all problems; therefore, some problems may be escaping the work-station. Defects exiting the station may overwhelm the system, eventually escaping and getting into the customer's hands. A weak system may rely too much on downstream inspection.

As the semester progresses Lego Lab students experience failure and begin to understand the myriad reasons they fail to meet the OEE objective. Through the A3 process, they expose likely causes, confirm the root cause, and develop countermeasures to achieve the Overall Equipment Effectiveness (OEE) goal. The countermeasures identified and implemented represent an Error-Proofed process design that allows the team to move toward achieving the OEE goal. This process is another element of Experiential Learning related to the Lean Manufacturing pillar of Jidoka.

CHAPTER 4: Findings

Introduction

Chapter 1 defines the study's purpose, statement of problem, research questions, limitations, and definitions of terms. Chapter 2 reviews the literature on higher education institutions teaching LM in simulated factory environments. Chapter 3 discusses research design, participants, learning environments (classroom vs lab), and data survey instruments. Chapter 4 reviews the findings of the study.

This chapter provides the results of a quantitative analysis based on students receiving Classroom Lectures and Experiential Learning in a Simulated Factor (CLELSF) vs. Students with Classroom Lectures (CL) only. Four statistical tests are conducted using two-sample t-tests. The analyses are used to answer the three research questions. The survey instrument measures student knowledge of Lean Manufacturing (LM) by sub-topic areas of (LM). A pre-class and post-class survey was taken to understand the efficacy of instruction.

Purpose of Study

A validated Experiential Learning (EL) approach in teaching Lean Manufacturing (LM) principles improves student knowledge. It ensures that students going to industry understand and can apply the Lean Manufacturing (LM) tools required to eliminate waste and redesign operating systems. Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165).

This study also supports educators in making a case for Simulated Factories (SF) to funding agencies.

When teaching Lean Manufacturing (LM), the importance of the Just-In-Time (JIT) sub-topic is clear, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation, Rother et al, 2003). The hesitancy of managers to utilize this most important tool is an integral part of this study leading to the formulation of one of the three research questions, which focused on Just-In-Time (JIT) knowledge with 16 questions of a 47-question survey related to Just-In-Time (JIT). These 16 questions were administered to independent sample groups: students engaged in classroom lectures and experiential learning in the Simulated Factory (CLELSF) and students with classroom lectures (CL) only.

The 47 questions survey represents four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10) and JIT (16). The questions are designed to test for differences between On-Campus and Distance students. It was expected that students engaged in (CLELSF) would show improvement in all sub-topic areas of Lean Manufacturing (LM) with more significant improvement in Just-In-Time (JIT) knowledge over students with (CL).

Research Questions

The following research questions were posed in the study:

RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

RQ3: Is there a performance difference between "On-Campus" students and "Distance" students?

Distance students represented the (CL) or "No Lab" independent sample in this study, while "On-Campus" students represented (CLELSF) or students with "Lab". There may be a difference between these two groups beyond instruction. In one limited data set, On-Campus students represent the Independent Sample (CL) or "No Lab" due to the COVID isolation period in which lab activities were canceled. This data set measures the JIT sub-topic questions only.

Overview of Statistical Tests

Four tests were conducted to compare the Pre- and Post-test survey results for students with Classroom Lecture and Experiential Learning in a Simulated Factor (CLELSF) vs. students with Classroom Lecture (CL) only. Boxplots were used to show differences graphically, and two-sample t-tests were used to compare the means of the two groups. When reviewing the data, "Lab" represents (CLELSF) students, and "No Lab" represents (CL) students.

Four Two-Sample T-Tests

Test 1: Pre and Post survey total scores for all sub-topic areas of Lean Manufacturing (LM) comparing the two independent groups, (CLELSF) and (CL). This test was conducted to understand the course's efficacy for all students.

μ_1: population mean of Total when Pre/Post = Post

μ_2: population mean of Total when Pre/Post = Pre

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

H_1: $\mu_1 - \mu_2 \neq 0$

The boxplots in Figure 37 show pre-and post-survey scores for all students, both On-Campus and Distance, to understand the overall course efficacy for all students. Tables 9 – 11 give the statistics for this test.

Figure 37

Comparative Analysis Boxplot of Pre and Post-Survey Scores for All Students

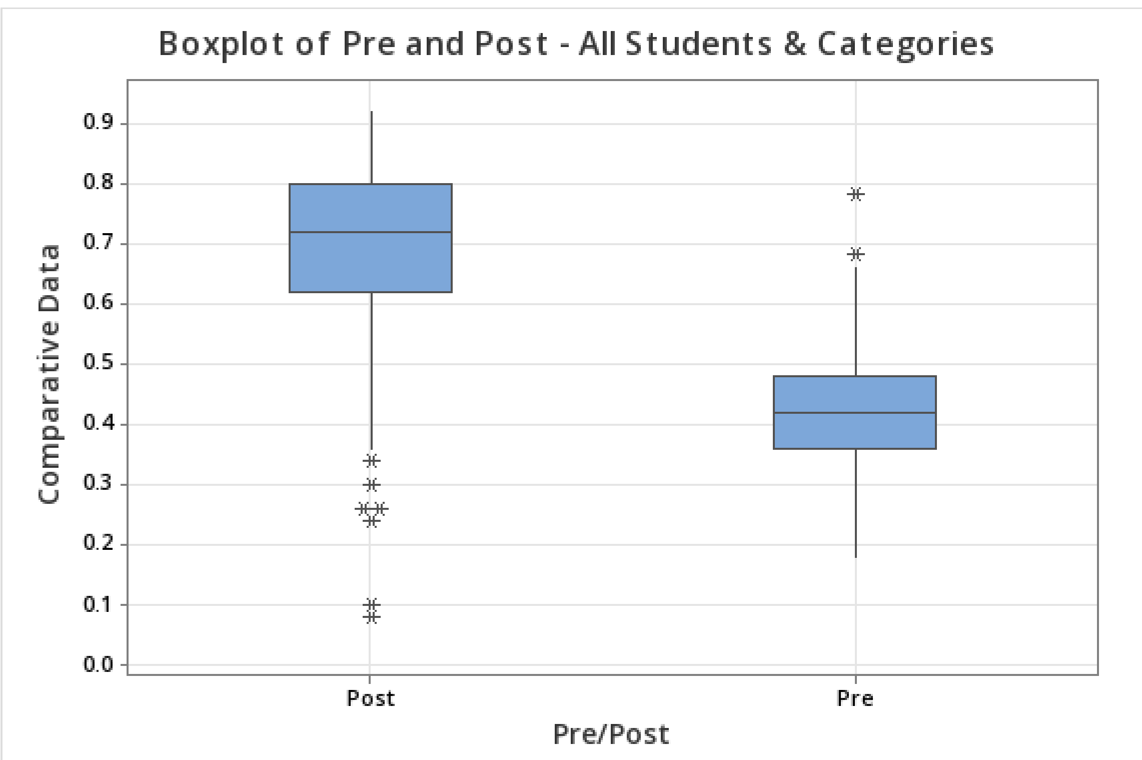


Table 9

Descriptive Statistics:

Survey	N	Mean	Std. Dev.	SE Mean
Post	171	0.682	0.157	0.012
Pre	245	0.4245	0.0906	0.0058

Table 10

Estimation of Difference

Difference	95% CI for Difference
0.2574	(0.2311, 0.2836)

Table 11

Null Hypothesis H_0: $\mu_1 - \mu_2 = 0$, *Alternative Hypothesis* H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
19.31	248	0.000

The Boxplot in Figure 37 compares all students' range and median scores (combined independent sample groups) before and after course instruction. The two-sample t-test was used to compare students' means before and after the Lean Manufacturing course to confirm learning without regard to treatment.

Since the null hypothesis was rejected, the data demonstrates a significant difference, $P<.001$, between student Lean Manufacturing (LM) knowledge before and after the course. This test does not answer a research question; instead, it establishes the overall efficacy of the course.

Test 2: Post survey scores, (CLELSF) vs (CL) for the Just-In-Time (JIT) sub-topic of Lean Manufacturing (LM). This unique data set involved On-Campus students only. Data were taken during a COVID isolation period. As a rule, all on-campus students participate in the Simulated Factory (SF). This unique data set allowed for comparison of like students (On-Campus). All other comparisons between (CLELSF) and (CL) involved On-Campus students vs Distance Students. This test answers RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

μ_1: population mean of when Lab = No

μ_2: population mean of when Lab = yes

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

H_1: $\mu_1 - \mu_2 \neq 0$

Figure 38 is a comparative analysis of student performance for the JIT subtopic element of Lean Manufacturing for those with lab vs without. This unique data set includes data obtained during the mandated COVID period when On-Campus students did not engage in lab activities. It is the only data set that compares On-Campus students with and without lab. The data is limited to the JIT set of questions only.

Figure 38

Comparative Analysis Boxplot of the JIT Sub-Topic for CLELSF vs. CL Students (On-Campus Students Only)

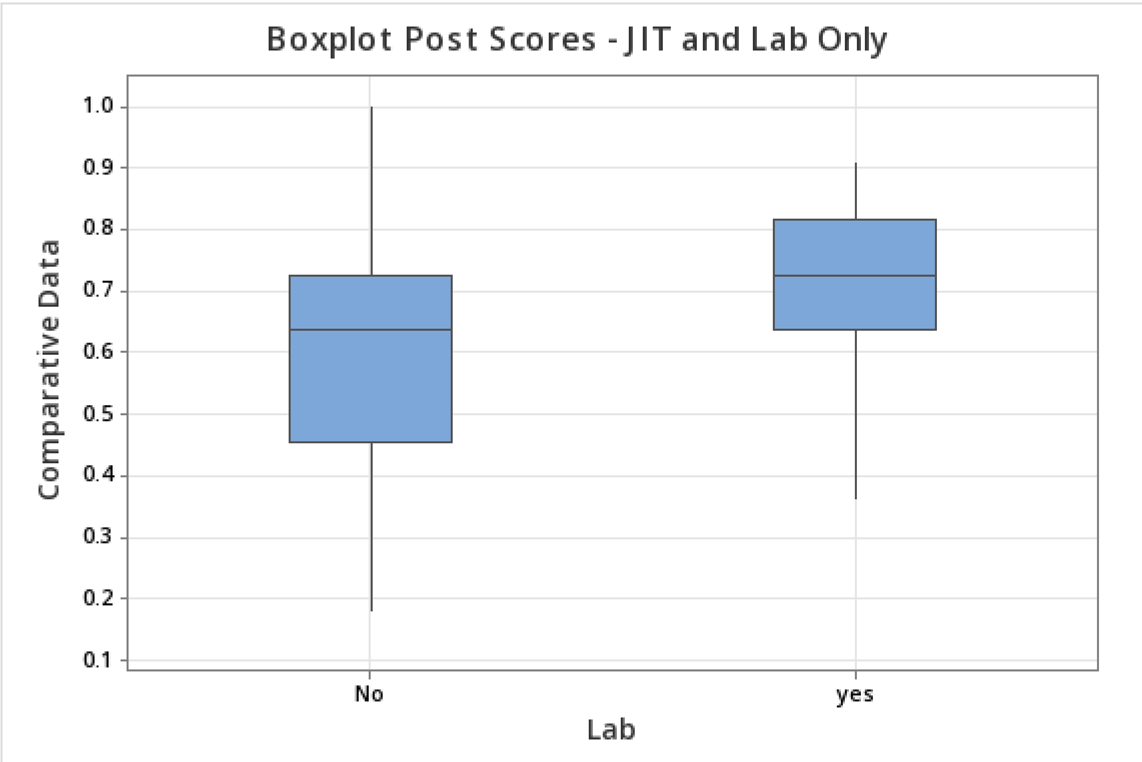


Table 12

Descriptive Statistics:

Lab	N	Mean	Std. Dev.	SE Mean
No	59	0.613	0.185	0.024
Yes	100	0.724	0.135	0.014

Table 13

Estimation for Difference

Difference	95% CI for Difference
-0.1104	(-0.1652, -0.0556)

Table 14

Null Hypothesis H_0: $\mu_1 - \mu_2 = 0$, Alternative Hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-4.00	95	0.000

The Boxplot in Figure 38 compares the range and median score of (CLELSF) students vs (CL) students for the Just-In-Time (JIT) sub-topic element of Lean Manufacturing.

The two-sample t-test was used to compare the means. This data set is limited to 100 students in the lab vs. 59 students without lab for On-Campus students only. These data were captured during a COVID-19-mandated isolation period. All On-Campus students are provided lab training as a rule, except during COVID isolation.

The null hypothesis was rejected, P<.001. The data demonstrates a significant difference in means between the two independent samples. This result is expected in all other Lean Manufacturing (LM) learning sub-topic areas.

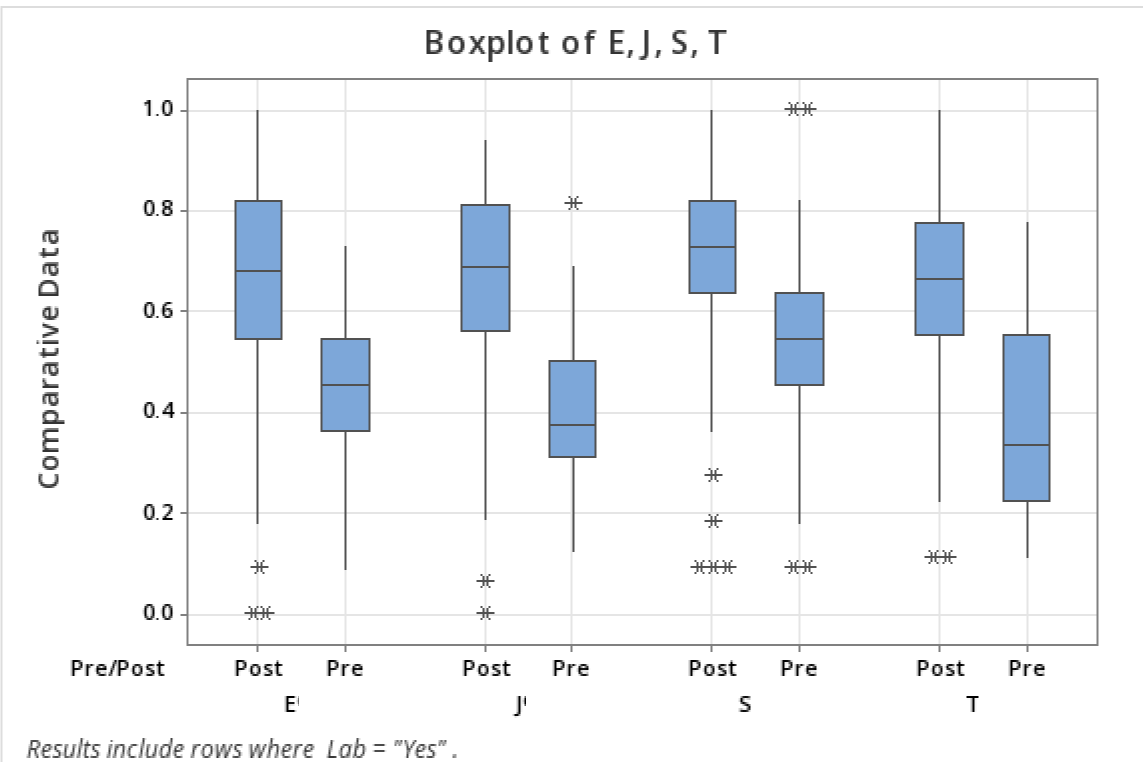
This result, therefore, answers the research question in the affirmative: RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Test 3: Pre and Post survey comparison of (CLELSF) and each Lean Manufacturing (LM) sub-topic. This data set involved On-Campus students only. Two-Sample t-tests were conducted to compare each sub-topic area individually to test RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a greater effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and TPS?

Figure 39 is a comparative analysis of knowledge for each sub-topic area of Lean. This data set involves CLELSF students only. The boxplots illustrate the rate of learning for each sub-topic element of LM.

Figure 39

Boxplot comparison of pre and post-survey scores for each subtopic area of LM, CLELSF students only



A two-sample t-test was used to compare the mean difference for each sub-topic area. The null hypothesis was rejected in all cases with P<.001 for each sub-topic at a 98% confidence level.

Table 15 shows JIT with a more significant estimated difference vs. Error Proofing and Standardization, .3017 vs. .1788 and .2203, respectively.

Table 15

Summary of Descriptive Statistics for each Sub-Topic of Lean Manufacturing (LM)

Strategy	Difference	98% CI for Difference	T-Value	DF	P-Value
JIT	.3017	(.2626, 0.3409)	18.03	280	<.001
Error Proofing	.1788	(.1361, .2214)	9.81	282	<.001
Standardization	.2203	(.1811, .2594)	13.15	339	<.001
TPS	.3057	(.2633, .3481)	16.84	326	<.001

All tests show a P-value<.001, indicating highly significant results. The t-value demonstrates the strength against the null hypothesis. The t-value of JIT, 18.03 vs. Error-Poofing, 9.81, Standardization 13.15, and TPS, 16.84, provide a better case against the null hypothesis, thus indicating a more significant difference in means between each sub-topic area. These results answer in the affirmative: RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a greater effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and TPS?

μ_1: population mean of **J** when Pre/Post = Post

μ_2: population mean of **J** when Pre/Post = Pre

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

H_1: $\mu_1 - \mu_2 \neq 0$

Table 16

Descriptive Statistics: J

Survey	N	Mean	Std. Dev.	SE Mean
Post	171	0.686	0.190	0.015
Pre	245	0.384	0.131	0.0084

Table 17

Estimation for Difference

Difference	98% CI for Difference
0.3017	(0.2626, 0.3409)

Table 18

Null Hypothesis H_0: $\mu_1 - \mu_2 = 0$, *Alternative Hypothesis* H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
18.03	280	0.000

Method

μ_1: population mean of **E** when Pre/Post = Post

μ_2: population mean of **E** when Pre/Post = Pre

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

Table 19

Descriptive Statistics: E

Survey	N	Mean	Std. Dev.	SE Mean
Post	171	0.642	0.206	0.016
Pre	245	0.463	0.143	0.0092

Table 20

Estimation for Difference

Difference	98% CI for Difference
0.1788	(0.1361, 0.2214)

Table 21

T-Value	DF	P-Value
9.81	282	0.000

μ_1: population mean of **S** when Pre/Post = Post

μ_2: population mean of **S** when Pre/Post = Pre

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

Table 22

Descriptive Statistics: S

Survey	N	Mean	Std. Dev.	SE Mean
Post	171	0.738	0.176	0.013
Pre	245	0.518	0.157	0.010

Table 23

Estimation for Difference

Difference	98% CI for Difference
0.2203	(0.1811, 0.2594)

Table 24

T-Value	DF	P-Value
13.15	339	0.000

μ_1: population mean of **T** when Pre/Post = Post

μ_2: population mean of **T** when Pre/Post = Pre

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

Table 25

Descriptive Statistics: T

Survey	N	Mean	Std. Dev.	SE Mean
Post	171	0.680	0.194	0.015
Pre	245	0.375	0.164	0.010

Table 26

Estimation for Difference

Difference	98% CI for Difference
0.3057	(0.2633, 0.3481)

Table 27

Null Hypothesis H_0: $\mu_1 - \mu_2 = 0$, *Alternative Hypothesis* H_1: $\mu_1 - \mu_2 \neq 0$

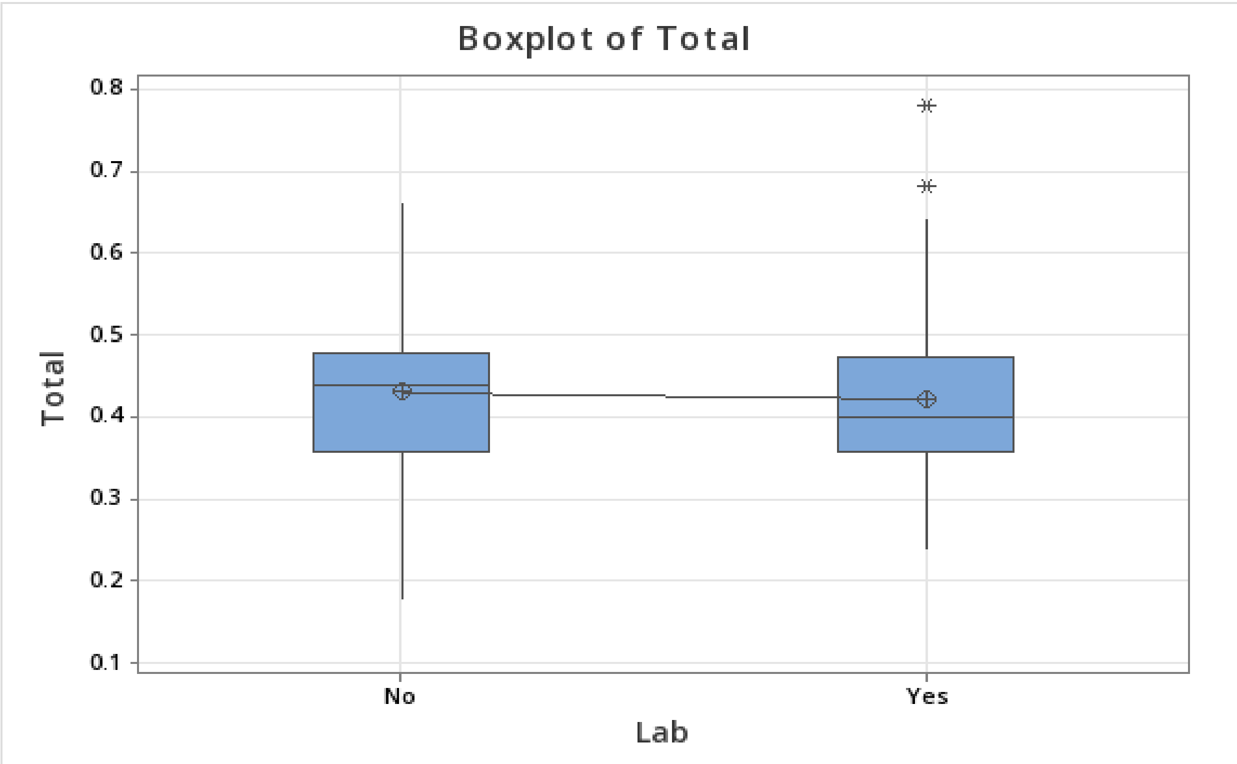
T-Value	DF	P-Value
16.84	326	0.000

Test 4: Test four was conducted to compare (CLELSF) vs (CL) total scores, including all sub-topic areas for pre- and post-survey results. This test was conducted to answer RQ3: Is there a performance difference between "On-Campus" students and "Distance" students?

Figure 40 compares pre-survey scores of LM knowledge for CLELSF vs. CL students. The test demonstrates that both groups, On-Campus and Distance, had similar knowledge of LM before taking the course.

Figure 40

Comparative Analysis of Pre-Course Scores for CLELSF and CL Students



μ_1: population mean of Total when Lab = No

μ_2: population mean of Total when Lab = Yes

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

Table 28

Descriptive Statistics: Total

Lab	N	Mean	Std. Dev.	SE Mean
No	77	0.4306	0.0911	0.010
Yes	168	0.4217	0.0905	0.0070

Table 29

Estimation for Difference

Difference	95% CI for Difference
0.0090	(-0.0157, 0.0337)

Table 30

Null Hypothesis H_0: $\mu_1 - \mu_2 = 0$, Alternative Hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

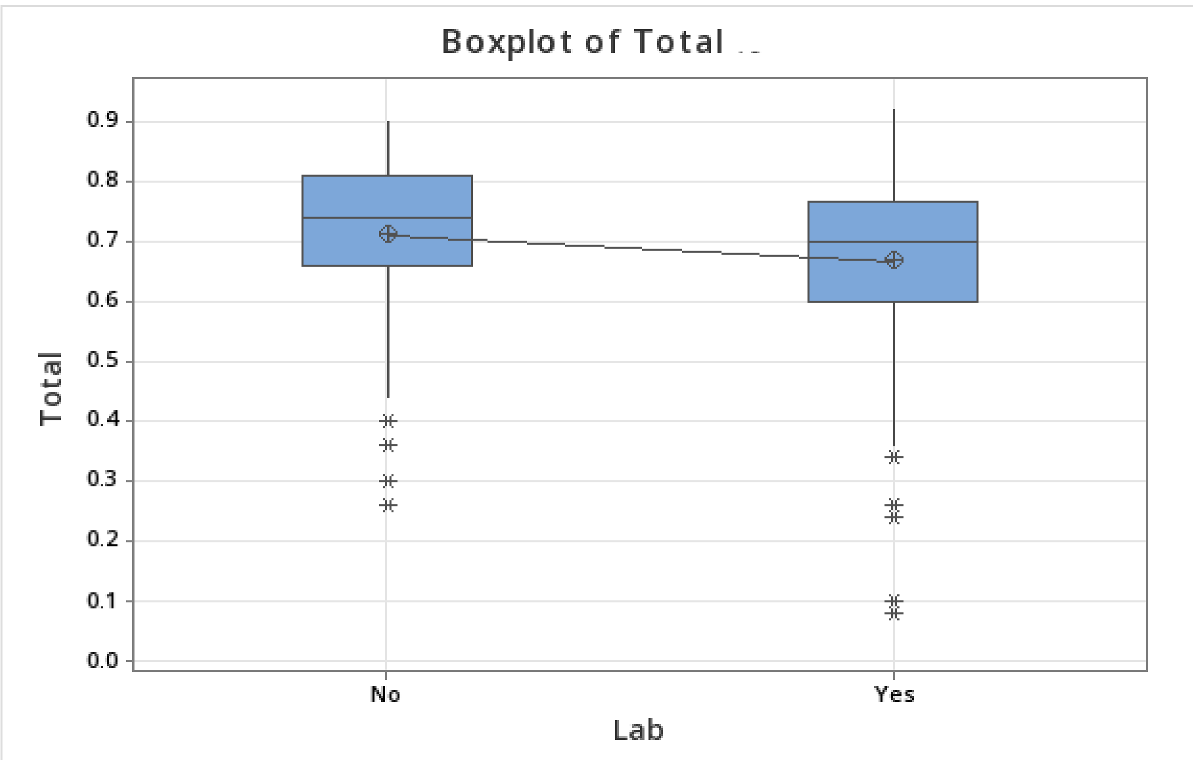
T-Value	DF	P-Value
0.72	146	0.474

The null is not rejected, P>.05. Strong evidence suggests no difference between the two independent samples, with a P value of .474. This test's result shows that the two groups had similar knowledge of Lean Manufacturing (LM) before taking the course.

Figure 41 compares post-survey scores of LM knowledge for CLELSF vs. CL students. The test demonstrates that both groups, On-Campus and Distance, show no statistical difference in knowledge of LM after taking the course.

Figure 41

Figure 5. Comparative Analysis of Post-Course Scores for (CLELSF) vs (CL) Students, On-Campus vs. Distance Students



μ_1: population mean of Total when Lab = No

μ_2: population mean of Total when Lab = Yes

Hypothesis:

H_0: $\mu_1 - \mu_2 = 0$

Table 31

Descriptive Statistics: Total

Lab	N	Mean	Std. Dev.	SE Mean
No	57	0.711	0.150	0.020
Yes	114	0.667	0.159	0.015

Table 32

Estimation for Difference

Difference	95% CI for Difference
0.0435	(-0.0056, 0.0927)

Table 33

Null Hypothesis H_0*:* $\mu_1 - \mu_2 = 0$*, Alternative Hypothesis* H_1*:* $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
1.75	118	0.082

The null is not rejected, P>.05. Test 2 established the efficacy (CLELSF) over (CE). It was expected that Test 4 would yield similar results. Test 2 answered in the affirmative for RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only? The explanation for this result answers in the affirmative for RQ3: Is there a performance difference between “On-Campus” students and “Distance” students?

Distance Students outperform On-campus Students for reasons not answered in this study. The independent sample and pre-survey scores are similar. Distance students can perform at the same level without the benefit of Experiential Learning in a Simulated Factory.

Summary

Four tests were conducted to answer the three research questions of this study. The first test does not address a research question but demonstrates that the Lean Manufacturing (LM) course improves overall knowledge of Lean. Tests 2, 3, and 4 answer research questions 1, 2, and 3, respectively.

Boxplots were used for all tests to show the differences between the two independent samples graphically: students engaged in Classroom Lecture and Experiential Learning in a Simulated Factory (CLELSF) and students with Classroom Lecture (CL) only.

Two Sample t-tests were used for all tests to understand the mean differences of the two independent sample groups (CLELSF) and (CL).

Four tests were conducted using Boxplots and Two-Sample t-tests to answer three research questions. Test 1 was conducted to evaluate the total combined learning for students engaged in (CLELSF) and (CL) by comparing Pre and Post survey scores for all sub-topic areas of Lean Manufacturing (LM); Test 1 confirmed with a 95% confidence level and $P<.001$, a difference between the pre-and post-survey scores. This test did not answer a research question; instead, it established the overall effectiveness of the Lean Manufacturing (LM) course.

Test 2 was conducted as a two-sample t-test to compare the JIT subtopic element of Lean Manufacturing knowledge for (CLELSF) vs (CL) students. This unique data set was limited to

100 students with lab vs. 59 students without lab for On-Campus students only. The data was captured during a COVID-mandated isolation period. All on-campus students are provided lab training as a rule, except for those in this period of COVID isolation.

The null was rejected, $P<.001$. The data demonstrates a significant difference between (CLELSF) vs (CL) students for the Just-In-Time (JIT) sub-topic area of Lean Manufacturing (LM). The result answered RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Test 3 was conducted to compare pre and post-survey scores for each sub-topic area of Lean Manufacturing for (CLELSF). Just-In-Time (JIT) had a more significant estimated difference vs. Error Proofing and Standardization, .3017 vs. .1788 and .2203, respectively. JIT also has a higher range than Error Proofing and Standardization.

All tests show $P<.001$, indicating highly significant results. The T-value demonstrates the strength against the null hypothesis. The T-Value of JIT, 18.03 vs. Error- Proofing, 9.81, Standardization 13.15, and TPS, 16.84, provide a better case against the null hypothesis, thus indicating a more significant difference in means between each sub-topic area.

The results of Test 3 answered RQ2 in the affirmative: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a greater effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and TPS?

Test 4 compared the means of Pre-course and post-course scores for (CLELSF) vs (CL) students. The null was not rejected, $P>.05$, in either case.

Test 2 established the efficacy of (CLELSF) over (CL). It was expected that Test 4 would yield similar results. Test 2 answered in the affirmative RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Test 4 results answered RQ3 in the affirmative: Is there a performance difference between “On-Campus” students and “Distance” students? Distance Students outperformed On-Campus Students for reasons not answered in this study. Both independent sample pre-survey mean scores are similar, .4306 and .4216, or Distance vs On-Campus students, indicating Distance students had no greater knowledge of Lean Manufacturing (LM) before the course. Distance student post-course mean, while not rising to the level of $P<.05$, does show a higher average**,** .711 vs .667.

This study did not set out to compare the differences between the participants of each group. It aimed to show the effectiveness of the Simulated Factory (SF) environment in providing Experiential Learning. While this was accomplished with the sub-topic data in Test 2, the result of Test 4 was unexpected, and it will be discussed in Chapter 5.

CHAPTER 5. Summary, Implications, and Recommendations for Future Studies

Introduction

Chapter 1 introduces the topics of Adult Education, Experiential Learning, Lean Manufacturing, and Simulated Factories. It defines the problem statement, Research Questions, Purpose of the Study, and Significance of the Study. It also discusses Study Limitations and defines terms. Chapter 2 presents a summary of Experiential Learning, Adult Education, and Lean Manufacturing and reviews higher education experiential Learning labs in Simulated Factory environments. Chapter 3 discusses the study's research design, data collection instrument, and statistical tools. Chapter 4 explained the research findings. Chapter 5 summarizes the findings and conclusions. The chapter also discussed study implications, limitations, and recommendations for future research.

Purpose of Study

A validated Experiential Learning (EL) approach in teaching Lean Manufacturing (LM) principles improves student knowledge. It ensures that students going to industry understand and can apply the Lean Manufacturing (LM) tools required to eliminate waste and redesign operating systems. Preparing students with lean knowledge before entering the manufacturing industry is vital to their initial success.

With recent advances and intense competition in the field of manufacturing, there is a great need to educate and employ qualified professionals. The need for a certification exam in lean manufacturing was revealed in a survey conducted on more than 1100 manufacturing industry respondents by the Society of Manufacturing Engineers (SME) (Hogan, 2005, p. 165). This study also supports educators in making a case for Simulated Factories (SF) to funding agencies.

When teaching Lean Manufacturing (LM), the importance of the Just-In-Time (JIT) sub-topic is clear, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation, Rother et al, 2003). The hesitancy of managers to utilize this most important tool is an integral part of this study leading to the formulation of one of the three research questions, which focused on Just-In-Time (JIT) knowledge with 16 questions of a 47-question survey related to Just-In-Time (JIT). These 16 questions were administered to independent sample groups: students engaged in classroom lectures and experiential learning in the Simulated Factory (CLELSF) and students with classroom lectures (CL) only.

The 47 questions survey represents four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10) and JIT (16). The questions are designed to test for differences between On-Campus and Distance students. It was expected that students engaged in (CLELSF) would show improvement in all sub-topic areas of Lean Manufacturing (LM) with more significant improvement in Just-In-Time (JIT) knowledge over students with (CL).

Research Questions

The following research questions were posed in the study:

RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-

Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

RQ3: Is there a performance difference between “On-Campus” students and “Distance” students?

Distance students represented the (CL) or “No Lab” independent sample in this study, while “On-Campus” students represented (CLELSF) or students with “Lab.” There may be a difference between these two groups beyond instruction. In one limited data set, On-Campus students represent the Independent Sample (CL) or “No Lab” due to the COVID isolation period in which lab activities were canceled. This data set measures the JIT sub-topic questions only.

Overview

This study examined the impact of an experiential approach to Lean Manufacturing education. A Simulated Factory at a southeastern university reinforced classroom lecture material. Two independent sample groups' pre and post-test knowledge of lean were compared to understand the difference between students engaged with Classroom Lecture (CL) and Experiential Learning in a Simulated Factory (CLELSF) vs students with Classroom Lecture (CL) only.

Of specific interest was the Lean Manufacturing sub-topic of Just-In-Time (JIT). JIT was of interest due to:

> Value Stream Mapping (VSM) is the most important step in the 10-step process of lean transformation (Rother et al, 2003). VSM is the primary Lean Manufacturing tool used to evaluate where to focus attention when implementing a system of JIT.

Taiichi Ohno sent senior managers to supplier locations to teach and implement Just-In-Time (JIT) methods. Past teaching attempts failed, and Ohno concluded that Just-In-Time (JIT) must be taught while being implemented at supplier locations.

Summary of Findings

The first statistical test did not answer one of the three research questions. The purpose of the test was to establish the effectiveness of the course for all students, both CL and CLELSF combined. The null was rejected. The data demonstrated a significant difference, P<.001, of student Lean Manufacturing (LM) knowledge before and after the course for all students, CL and CLELSF.

The second statistical test answered in the affirmative for Research Question 1 regarding the efficacy of the Experiential Learning approach. The data set was taken during COVID isolation and focused only on the JIT sub-topic of Lean Manufacturing. This data set was the only data available to compare the same student type (On-campus) with both (CL) and (CLELSF) treatment. The JIT set of survey questions represented 16 questions of the 47-question survey used for all other tests. The 47-question survey tests four sub-topic areas of Lean Manufacturing (LM): general knowledge of Lean Manufacturing or Toyota Production System (TPS) (9), Standardization (12), Jidoka (10), and JIT (16). The null is rejected, P<.001. The data demonstrates a significant difference in means between the two independent samples, JIT knowledge of (On-campus) students engaged in (CL) vs. (CLELSF).

The third statistical test involved a Two-Sample t-test used to compare the difference in means for each sub-topic area. This data set involved CLELSF students only. The null was rejected with P <.001 for each sub-topic at 98% confidence level. JIT showed a greater estimated difference vs. Error Proofing and Standardization, .3017 vs. .1788 and .2203, respectively. This answered RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

Test 2: Post survey scores, (CLELSF) vs (CL) for the Just-In-Time (JIT) sub-topic of Lean Manufacturing (LM). This unique data set involved On-Campus students only. Data was taken during a COVID isolation period. All On-Campus students participate in the Simulated Factory (SF) as a rule. This unique data set allowed for comparison of like students (On-Campus). All other comparisons between (CLELSF) and (CL) involved On-Campus students vs Distance Students. This test answers RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Figure 2 is a comparative analysis of student performance for the JIT subtopic element of Lean Manufacturing for those with lab vs without. This unique data set includes data obtained during the mandated COVID period when On-Campus students did not engage in lab activities. It is the only data set that compares On-Campus students with and without lab. The data is limited to the JIT set of questions only. Research Question 2 confirmed that knowledge of the sub-topic area of JIT improved at a greater rate than the other sub-topic areas of Lean.

The fourth statistical test was conducted to compare (CLELSF) vs (CL) total scores, including all sub-topic areas for pre-and post-survey results. This test was conducted to answer RQ3: Is there a performance difference between “On-Campus” students and “Distance” students? The null was not rejected, $P>.05$. Strong evidence that suggests no difference between the two independent samples with a P value = .474. This test's result makes clear that the two groups had similar knowledge of Lean Manufacturing (LM) before taking the course. The test demonstrates that both groups, On-Campus and Distance, show no statistical difference in knowledge of LM after taking the course.

Research Questions Answered

The statistical test answered positive to the research questions RQ1: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) improve their overall Lean Manufacturing (LM) knowledge at a greater rate than students with traditional classroom instruction (CL) only?

Similarly, the statistical test gave a positive answer to RQ2: Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM); Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS?

However, the statistical test gave a negative answer to RQ3: Is there a performance difference between “On-Campus” students and “Distance” students?

The results of this study are surprising. While the experiential approach improved efficacy in the second test, the distance students (CL) performed at the same level as On-campus students (CLELSF).

This can be explained given that Distance students (CL) are considered adults (See Table 34). Their life experience, ability to learn at their own schedule (Lectures are recorded and can be viewed at any time), and overall motivation to use knowledge for life purposes can explain how they overcome not having the benefit of the experiential approach to equal the performance of students with both classroom lecture and experiential learning in a simulated factory (see Table 34).

Table 34

Student demographics – On-Campus vs. Distance

Survey Response	On-Campus	Distance
Married	7%	47%
Full Time Employed	16%	100%
Children	9%	41%
25 years of age or older	11%	94%
Lean Experience prior to class	41%	83%

Note: Limited survey based on 17 Distance students vs. 46 On-Campus

Implications

The results of this study are surprising. While the experiential approach showed improved efficacy, the distance student (CL) performed at the same level as the On-campus student (CLELSF), possibly due to their status as Adult Learners.

This study demonstrates the value of Experiential Learning for Lean Manufacturing education. Students and companies can benefit from an Experiential approach. Of particular importance in teaching the most important sub-topic of Lean Manufacturing, Just-In-Time.

Do students engaged in both classroom lectures and Experiential Learning in a Simulated Factory (CLELSF) show a more significant effect on learning for the sub-topic area of Just-In-Time (JIT) over other tested sub-topic areas of Lean Manufacturing (LM), Standardization, Jidoka, and general knowledge of Lean Manufacturing (LM) or TPS? This question was answered in the affirmative. Students of academia and industry will benefit at a greater rate with an experiential approach to ensure an understanding of JIT. The JIT sub-topic of Lean is difficult to teach and a very important factor when implementing Lean systems, given that the primary tool for (JIT) implementation, Value Stream Mapping (VSM), is the most important step in the 10-step process of lean transformation (Rother et al.; J., 2003). Forward by Jim Womack.

Educators may use this study to support requests from funding agencies to construct Simulated Factories. This study is significant as no other study focused on Lean Manufacturing education identified in the literature validates the approach using quantitative methods with a significant sample size.

This study did not initially focus on Adult Learners. However, the data demonstrates that Adult Learners can overcome the absence of the experiential approach due to their advantage in the educational process. This result may be useful to other researchers' efforts to understand the impact Adult Learner status has on the learning process.

Limitations

Due to the Adult Learner status of the CL independent variable, the validation of the experiential approach could only be examined for a subset of the total data available, the JIT sub-topic of Lean Manufacturing survey questions, 16 of 47. This was possible due to a COVID restriction on lab use. All respondents (CL and CLELSF) were On-Campus students for this test only. While the sample size was adequate, 59 students CL vs. 100 students CLELSF, it was assumed the impact of the experiential learning approach would translate to all sub-topic areas of Lean Manufacturing.

Classroom Lectures were viewed live in the classroom for On-Campus students only. Distance students received a Panopto Recording of lectures. Live lectures may be an advantage for On-Campus students. However, the flexibility to view lectures that best fit the Adult Learners' schedule may be an advantage. The effects of live vs recorded lectures were not considered in this study.

What is not understood is the level of learning that would have been possible for distance students with the experiential learning approach. Although the data showed that Distance students performed as well as On-campus students, the question remains: How would they perform if engaged in the experiential approach? The lab environment likely helps students understand the interdependence of all lean systems acting together.

People are the foundation of the Lean House. On-campus students were placed on teams with a team leader structure. Teams worked together to evolve their OEE performance throughout the semester. This study cannot assess what Distance students may have missed by not being engaged in the lab activity.

The lab activity adds another level of exposure to the Lean Manufacturing subject matter. On-campus students supplement the knowledge obtained in the classroom with another experience around the same subject matter. This study did not measure the impact of missing this redundant information.

Recommendation for Future Study

Ensure both independent sample groups are similar. While this study's research questions were answered successfully, the adult learner confounding factor complicated the result and did not allow for all sub-topics of Lean Manufacturing to be tested on like students.

Evaluate the individual based on learning style. This study did not track the individual scores for pre and post-results. Adding the student's preferred learning style would further help to understand how to tailor the curriculum to benefit the most students. Include a longitudinal study by arranging to have a statistically significant group of students agree to retake the exam at a later date, perhaps a year out, to understand learning retention. Experiential Learning methods appear to improve knowledge retention (Prussia & Weis, 2003-2004, p. 403), (Forte-Celaya et al., 2020).

The survey in this study was developed based on test questions utilized in class. It is recommended that a survey be created to mimic a Lean Manufacturing certification exam, such as the Society of Manufacturing Engineering certification.

Add a component to the research for the development of a course evaluation methodology that breaks down elements of the course and evaluates the efficacy of instruction. While the approach of this study was to understand the impact of experiential learning for Lean

Manufacturing, the methodology of understanding how well students learn for all aspects of the course can be beneficial for subject matter from other courses.

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Appendix A: Survey Questions

Question 1 – CI1: PDCA is an acronym for Plan Design Check Act.

True False

Question 2 – JIT1: What is Heijunka?

Another word for Kanban

Fixed size batch production

Production smoothing to avoid large batches or swings in volume.

None of the above

Question 3 – JIT2: How would you describe the time difference between Takt Time and Cycle Time?

Allowance

Waste

OEE

All of the above

Question 4 – JIT3: To minimize or eliminate a warehouse, the goal must be to produce any product type desired each cycle. The most important consideration to accomplish this is:

Flexibility

Quality

Capacity

Efficiency

Question 5 – JIT4: A pacemaker process......

Receives its products from supermarkets controlled by MRP systems.

Is always a bottleneck, requiring constant supervision.

Ensures that all processes downstream are controlled by supermarket pull systems.

Responds to the external customer, and is the point at which production is scheduled.

Question 6 – JIT5: A key process designed to improve flexibility to product mix is:

JIT

Kanban

SMED

Jidoka

Question 7 – JIT6: A process that helps identify waste in a system is:

Standard Work

Andon

Value Stream Mapping

PDCA

Question 8 – JIT7: Lead Time is a product of:

Cycle Time & Inventory

WIP & Throughput Rate

The summation of all cycle times

Takt Rate and WIP

Question 9 – JIT8: Sub Assembly Cells provide ....

Quicker Cycle Times

Error Proof Processes

Higher Inventory

<u>Flexibility to Volume Changes</u>

Question 10 – Standardization1: Who said: "where there is no standard, there can be no kaizen?"

<u>Taiichi Ohno</u>

Shigeo Shingo

Henry Ford

W. Edwards Deming

Question 11 – TPS1: Lean Manufacturing and Six Sigma are essentially the same disciplines.

True <u>False</u>

Question 12 – Standardization2: It is better for an operator to take it upon themselves to modify how a job is performed if they know of an improved quality method rather than wait for a process change?

True <u>False</u>

Question 13 – Jidoka1: After an engine is assembled, it is validated with a full hot test. This is a form of Jikoka.

True <u>False</u>

Question 14 – Standardization3: The A3, 5 Why and Six Sigma are examples of:

Standardized Thinking

Standardized Work

Standardized Facility

Standardized Management Work

Question 15 -Standardization4: It is a better scenario for an operator is to take it upon themselves to modify how a job is performed if they know of an improved quality method, rather than waiting for a change?

True False

Question 16 – Standardization5: Another way to refer to 5S is the Standardization of the factory.

True False

Question 17 – Standardization6: The origin of standard work relates to…

Manufacturing Cells

The Automatic Power Loom

Plan Do Check Act (PDCA)

Sub Assembly Cells

Question 18 – Standardization7: The Scientific method involves a systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses. This aspect of Lean supports the Scientific Method:

Jidoka

MUDA

Standardized Work

PDCA

Question 19 – TPS2: In a Manufacturing Cell the team member adds value vs. the sub-assembly cell.

True False

Question 20 – Standardization8: Five S presented as a standardization method relates to:

Standardized Work

Standardized Facility

Standardized Thinking

Standardized Management Work

Question 21 – Standardization9: Five S order is..

Shine, Sort, Set In Order, Standardize and Sustain

Sanitize, Standardize, Sort, Set In Order and Shine

Sort, Set In Order, Shine, Standardize and Sustain

Sort, Standardize, Set In Order Shine and Sustain

Question 22 – Standardization10: The Five Why Problem-Solving Method is an example of Standardized Thinking.

True   False

Question 23 – JIT9: Supermarkets are a strategy used when continuous flow cannot be accomplished.

True   False

Question 24 – Standardization11: Choose the answer that most relates to the lecture. Standards are vital to continuous improvement because:

The company must have rules for team members to follow.

Standards create a reliable system.

Standards assure the system is controlled to facilitate experimentation.

We don’t want team members to think.

Question 25 – JIT10:

Before SMED:

Batch Size	Setup Time	Setup Cost Per Unit
1000	4 hrs / $250 per hr	$ 1
100	4 hrs / $250 per hr	$10
10	4 hrs / $250 per hr	$100

After SMED:

Selection	Batch Size	Setup Time	Setup Cost Per Unit
A	1000	30 minutes/ $250 per hr	$.125
B	100	30 minutes/ $250 per hr	$1.25
C	10	30 minutes/ $250 per hr	$12.50

From the SMED improvement above, which batch size should we now run given customer demand can be satisfied with 10, 100 or 1000?

1000 <u>10</u> 100

Question 26 – JIT11: What is the proper order sequence of a SMED project?

Determine the current state of changeover, B. define external and internal requirements, C. move internal elements to external where possible, D. Optimize all elements of changeover.

Define external and internal requirements, B. move external to internal where possible, C. Optimize all elements of changeover, D. Determine the current state of changeover.

Determine the current state of changeover, B. define external and internal requirements, C. Optimize all elements of changeover, D. move internal to external where possible.

Determine current state of changeover, B. Define external and internal requirements C optimize all elements of changeover, D. Move external to internal where possible.

Question 27 – JIT12: SMED falls under the Jidoka pillar of the Lean House because it helps to correct quality issues in process.

True False

Question 28 – JIT13: External elements can be executed only while the machine is down.

True False

Question 29 – JIT14: How many of the seven guidelines of value stream mapping, SMED improves:

<u>4</u>

3

1

2

Question 30 – TPS2: In terms of the 3 M's of waste, Mura = :

Overburden

<u>Unevenness</u>

None of the above

Waste

Question 31 – TPS3: The standard for value-added work is:

The product less transportation costs

<u>The customer is willing to pay for the element of work related to the product.</u>

An element of work that is required to produce the product.

Product without defects

Question 32 – TPS4: Inspection is value-added because it assures the product meets customer requirements.

True <u>False</u>

Question 33 – TPS5: The difference between Cycle Time and Takt Time can be thought of as:

Overproduction

MUDA

Distance from Perfection

All the above

Question 34 – JIT15: The Pacemaker process should be as close to the beginning of the process as possible.

True False

Question 35 – TPS6: Of the seven wastes, Ohno considers inventory as the number one waste.

True False

Question 36 – Jidoka2: Detection is a form of Jidoka.

True False

Question 37 – Jidoka3: Mistake Proofing means a defect cannot be made.

True False

Question 38 – Jidoka4: Severity x Occurrence x Detection = 1000, means the process or design is unlikely to fail.

True False

Question 39 – Jidoka5: Using proper problem-solving tools, we can reduce Severity thereby reducing the Risk Priority Number.

True False

Question 40 – Jidoka6: A team member torques a fastener, the torque is low and the tool indicates a failure with a red light, this is a form of Mistake-Proofing in the category of:

Control

Warning

Operational

Question 41- Jidoka7: Which item below is a PFMEA initiative.

A new torque tool that stops the line when a defect occurs.

The oil sump has a locating pin added to eliminate improper installation.

Question 42 – Jidoka8: The weakest method of control is Procedural or Standard Work Instructions.

True False

Question 43 – Jidoka9: Product Inspection is an unacceptable strategy of protecting product quality and should only be used as a last resort.

True False

Question 44 – Jidoka10: The ability of the human mind to unscramble letters and still make sense of the paragraph is ideal for product inspection to assure quality.

True False

Question 45 – Standardization12: Within the Toyota System, standard work originated with:

The Automatic Loom

5S

Manufacturing Cells

5 Whys

Question 46 – Jidoka11: An RPN Threshold is the risk priority number the organization is trying to exceed.

True False

Question 47 – TPS7: What are the two pillars of the Toyota Production System?

Jidoka / Just-In-Time

Jidoka / Continuous Improvement

Respect for People / Just-In-Time

Continuous Improvement / Respect for People

Question 48 – CI2: Continuous Improvement can best be characterized as:

Standardization

PDCA

Respect for People

Jidoka

Question 49 – JIT16: What mass production method typically violates Taiichi Ohno's number one waste when used to schedule production?

MRP Planning

Moving Assembly Line

Specialized Labor

High Turnover

Question 50 – TPS8: “The Toyota Way” defined key principles of the Toyota culture. What are they?

Just-In-Time and Jidoka

Just-In-Time, Jidoka, Respect for people and Continuous Improvement

<u>Respect for people and Continuous Improvement</u>

None of the above

Question 51- Academic Status: graduate or undergraduate?

Undergraduate

Graduate

Question 52 - Lean experience prior to class: No experience, 6 months to 1 year, More than 1 year.

No Experience

6 months to 1 year

Over 1 year

Question 53 - Please indicate your gender (Male, Female, Non-Binary, prefer not to answer)

Group of answer choices

Female

I prefer not to answer.

Male

Non-Binary

Appendix B: A3 Problem Solving Document

TIGER MOTORS
LEAN EDUCATION CENTER

A3

Title

Background

Current Conditions Date

Goal

Analysis

Recommendation

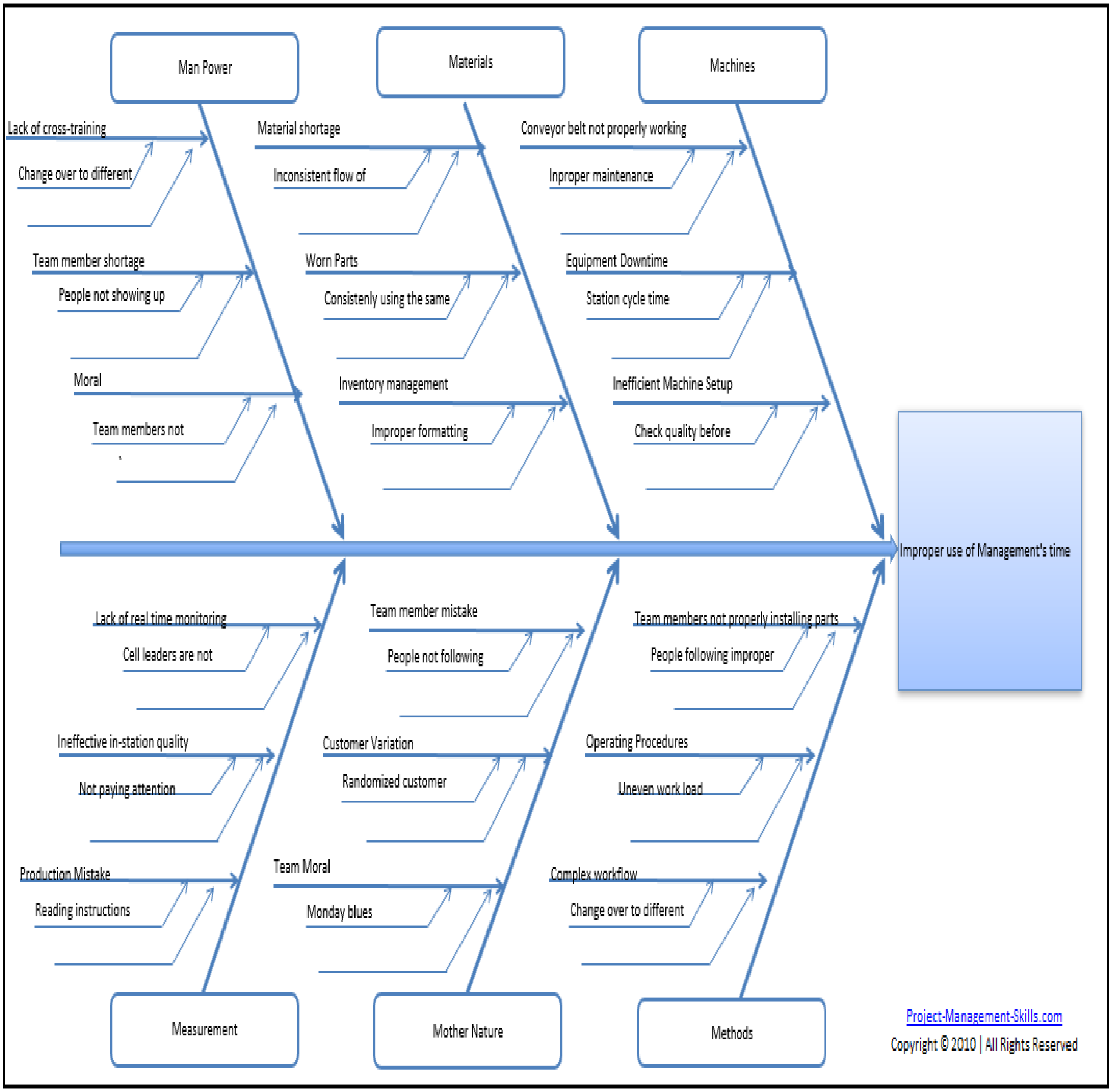
Plan

Problem	Task	Resp.	Logged	Due

Yellow = Current | Green = Completed On Time | Red = Overdue

Follow-Up

Appendix C: Fishbone Diagram



Appendix D: Five Why Analysis

Problem Statement			
Why is there so much Idle for management			
	Why	→	**Answer: Because...**
1	Why does management have idle time during production runs?	↙	There is a lack of real time monitoring of the process.
2	Why is there a lack of real time monitoring of the process?	→ ↙	Proper in-station quailty is not being utilized.
3	Why is proper in-station quailty is not being utilized?	→ ↙	Cell leaders and managers are not enforcing in-station quality like it should be.
4	Why are cell leaders and management not enforcing in-station quality?	→ ↙	There is a lack of checks and balances throughout the process.
5	Why is there a lack of checks and balances throughout the process?	→ ↙	There is not a concrete way of tracking where the defects are coming from.
Suspected Root Cause			
Lack of real time tracking of what is happening in the process			

Appendix E: Approved IRB

Revised 09/13/2023

1

AUBURN UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM (HRPP)

EXEMPT REVIEW APPLICATION

For assistance, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: IRBAdmin@auburn.edu Web Address: http://www.auburn.edu/research/vpr/ohs
Submit completed form and supporting materials as one PDF through the IRB Submission Page
Hand written forms are not accepted. Where links are found hold down the control button (Ctrl) then click the link.

1. Project Identification **Today's Date: May 24, 2024**

Anticipated start date of the project: December 19, 2019 Anticipated duration of project: 5 Years

a. **Project Title:** Statistical Validation of Experiential Learning vs Traditional Classroom Lecture for Lean Manufacturing.

b. **Principal Investigator (PI):** Tom Devall Degree(s): Masters: UAH – MAS, Auburn - EDS
Rank/Title: Director Department/School: Industrial and Systems Engineering

c. **Role/responsibilities in this project:** Student Dissertation
Preferred Phone Number: 334.740.3905 AU Email: devall@auburn.edu

Faculty Advisor Principal Investigator (if applicable): Dr. Maria Witte
Rank/Title: Associate Dean of the Graduate School Department/School: Educational Foundations, Leadership and Technology
Role/responsibilities in this project: Committee Chair
Preferred Phone Number: (334) 844-0299 AU Email: wittemm@auburn.edu

Department Head: William Murrah Department/School: Educational Foundations, Leadership and Technology
Preferred Phone Number: (334) 844-3806 AU Email: wmm0017@auburn.edu
Role/responsibilities in this project: No Role or Responsibility

d. **Project Key Personnel –** Identify all key personnel who will be involved with the conduct of the research and describe their role in the project. Role may include design, recruitment, consent process, data collection, data analysis, and reporting. (To determine key personnel, see decision tree). *Exempt determinations are made by individual institutions; reliance on other institutions for exempt determination is not feasible. Non-AU personnel conducting exempt research activities must obtain approval from the IRB at their home institution.*

Key personnel are required to maintain human subjects training through CITI. Please provide documentation of completed CITI training, with course title(s) and expiration date(s) shown. As a reminder, both IRB and RCR modules are required for all key study personnel.

Name: Tom Devall Degree(s): Masters: UAH – MAS, Auburn - EDS
Rank/Title: Director, Mfg. Initiatives Department/School: Industrial and Systems Engineering
Role/responsibilities in this project: Student Dissertation

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: Click or tap here to enter text.
- Plan for IRB approval for non-AU affiliated personnel? Click or tap here to enter text.
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: Click or tap here to enter text.
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU basic RCR Training 1/15/2027
IRB #2 Social and Behavioral Emphasis 11/30/2026

The Auburn University Institutional Review Board has approved this Document for use from 05/23/2024 to ---------- Protocol # 24-890 EX 2405

Name: Click or tap here to enter text. Degree(s): Click or tap here to enter text.
Rank/Title: Choose Rank/Title Department/School: Choose Department/School
Role/responsibilities in this project: Click or tap here to enter text.
- AU affiliated? ☐ Yes ☐ No If no, name of home institution: Click or tap here to enter text.
- Plan for IRB approval for non-AU affiliated personnel? Click or tap here to enter text.
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☐ No
- If yes, briefly describe the potential or real conflict of interest: Click or tap here to enter text.
- Completed required CITI training? ☐ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised EXEMPT application form.
- If YES, choose course(s) the researcher has completed: Choose a course Expiration Date
Choose a course Expiration Date

Name: Click or tap here to enter text. Degree(s): Click or tap here to enter text.
Rank/Title: Choose Rank/Title Department/School: Choose Department/School
Role/responsibilities in this project: Click or tap here to enter text.
- AU affiliated? ☐ Yes ☐ No If no, name of home institution: Click or tap here to enter text.
- Plan for IRB approval for non-AU affiliated personnel? Click or tap here to enter text.
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☐ No
- If yes, briefly describe the potential or real conflict of interest: Click or tap here to enter text.
- Completed required CITI training? ☐ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised EXEMPT application form.
- If YES, choose course(s) the researcher has completed: Choose a course Expiration Date
Choose a course Expiration Date

e. **Funding Source** – Is this project funded by the investigator(s)? Yes ☐ No ☒
Is this project funded by AU? Yes ☐ No ☒ If YES, identify source Click or tap here to enter text.
Is this project funded by an external sponsor? Yes ☐ No ☒ If YES, provide name of sponsor, type of sponsor (governmental, non-profit, corporate, other), and an identification number for the award.
Name: Click or tap here to enter text. Type: Click or tap here to enter text. Grant #: Click or tap here to enter text.

f. List other AU IRB-approved research projects and/or IRB approvals from other institutions that are associated with this project. Describe the association between this project and the listed project(s):
None

2. Project Summary

a. Does the study *TARGET* any special populations? Answer YES or NO to all.

Minors (under 18 years of age; if minor participants, at least 2 adults must be present during all research procedures that include the minors)	Yes ☐ No ☒
Auburn University Students	Yes ☒ No ☐
Pregnant women, fetuses, or any products of conception	Yes ☐ No ☒
Prisoners or wards (unless incidental, not allowed for Exempt research)	Yes ☐ No ☒
Temporarily or permanently impaired	Yes ☐ No ☒

b. Does the research pose more than minimal risk to participants? Yes ☐ No ☒

If YES, to question 2.b, then the research activity is NOT eligible for EXEMPT review. Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research is not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or test. 42 CFR 46.102(i)

c. Does the study involve any of the following? *If YES to any of the questions in item 2.c, then the research activity is NOT eligible for EXEMPT review.*

Procedures subject to FDA regulations (drugs, devices, etc.)	Yes ☐ No ☒
Use of school records of identifiable students or information from instructors about specific students.	Yes ☒ No ☒
Protected health or medical information when there is a direct or indirect link which could identify the participant.	Yes ☐ No ☒
Collection of sensitive aspects of the participant's own behavior, such as illegal conduct, drug use, sexual behavior or alcohol use.	Yes ☐ No ☒

d. Does the study include deception? Requires limited review by the IRB* Yes ☐ No ☒

3. MARK the category or categories below that describe the proposed research. Note the IRB Reviewer will make the final determination of the eligible category or categories.

☒ 1. Research conducted in established or commonly accepted educational settings, involving normal educational practices. The research is not likely to adversely impact students' opportunity to learn or assessment of educators providing instruction. 104(d)(1)

☒ 2. Research only includes interactions involving educational tests, surveys, interviews, public observation if at least ONE of the following criteria. (The research includes data collection only; may include visual or auditory recording; may NOT include intervention and only includes interactions). **Mark the applicable sub-category below (i, ii, or iii). 104(d)(2)**

☒ (i) Recorded information cannot readily identify the participant (directly or indirectly/ linked);
OR
- surveys and interviews: no children;
- educational tests or observation of public behavior: can only include children when investigators do not participate in activities being observed.

☐ **(ii)** Any disclosures of responses outside would not reasonably place participant at risk; **OR**

☐ **(iii)** Information is recorded with identifiers or code linked to identifiers and IRB conducts limited review; no children. **Requires limited review by the IRB.***

☐ 3. Research involving Benign Behavioral Interventions (BBI)** through verbal, written responses including data entry or audiovisual recording from adult subjects who prospectively agree and ONE of the following criteria is met. (This research does not include children and does not include medical interventions. Research cannot have deception unless the participant prospectively agrees that they will be unaware of or misled regarding the nature and purpose of the research) **Mark the applicable sub-category below (A, B, or C).** 104(d)(3)(i)

☐ **(A)** Recorded information cannot readily identify the subject (directly or indirectly/ linked); **OR**

☐ **(B)** Any disclosure of responses outside of the research would not reasonably place subject at risk;
OR

☐ (C) Information is recorded with identifies and cannot have deception unless participants prospectively agree. **Requires limited review by the IRB.***

☐ **4.** Secondary research for which consent is not required: use of identifiable information or identifiable bio-specimen that have been or will be collected for some other 'primary' or 'initial' activity, if one of the following criteria is met. Allows retrospective and prospective secondary use. **Mark the applicable sub-category below (I, II, III, or IV).** 104 (d)(4)

☐ **(I)** Bio-specimens or information are publicly available;

☐ **(II)** Information recorded so subject cannot readily be identified, directly or indirectly/linked investigator does not contact subjects and will not re-identify the subjects; OR

☐ **(III)** Collection and analysis involving investigators use of identifiable health information when us is regulated by HIPAA "health care operations" or "research" or "public health activities and purposes" (does not include bio-specimens (only PHI and requires federal guidance on how to apply); OR

☐ **(IV)** Research information collected by or on behalf of federal government using government generated or collected information obtained for non-research activities.

☐ **5.** Research and demonstration projects which are supported by a federal agency/department AND designed to study and which are designed to study, evaluate, or otherwise examine: (I)public benefit or service programs; (II) procedures for obtaining benefits or services under those programs; (III) possible changes in or alternatives to those programs or procedures; or (IV) possible changes in methods or levels of payment for benefits or service under those programs. (must be posted on a federal web site). 104.5(d)(5) (must be posted on a federal web site)

☐ **6.** Taste and food quality evaluation and consumer acceptance studies, (I) if wholesome foods without additives and consumed or (II) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture. The research does not involve prisoners as participants. 104(d)(6)

**Limited IRB review – the IRB Chair or designated IRB reviewer reviews the protocol to ensure adequate provisions are in place to protect privacy and confidentiality.*

***Category 3 – Benign Behavioral Interventions (BBI) must be brief in duration, painless/harmless, not physically invasive, not likely to have a significant adverse lasting impact on participants, and it is unlikely participants will find the interventions offensive or embarrassing.*

**** Exemption categories 7 and 8 require broad consent. The AU IRB has determined the regulatory requirements for legally effective broad consent are not feasible within the current institutional infrastructure. EXEMPT categories 7 and 8 will not be implemented at this time.*

4. Describe the proposed research including who does what, when, where, how, and for how long, etc.

a. Purpose

To evaluate the effectiveness of Lecture and Lab Activity vs Online students with the same lecture material (recorded Panopto video), without the benefit of a lab. Testing the effectiveness the lab activity on learning. Students take an ungraded pre-class and post-class survey covering course material. While names are recorded via Canvas, the data is pulled for analysis without names. In Classroom and Lab. Survey on Canvas. Survey takes approximately 20 minutes Pre and Post. Course Professor, Tom Devall to accumulate data for analysis.

b. Participant population, including the number of participants and the rationale for determining number of participants to recruit and enroll. Note if the study enrolls minor participants, describe the process to ensure more than 1 adult is present during all research procedures which include the minor.
All students, over multiple semesters. Current total surveys for both pre and post exam is 478.

c. Recruitment process. Address whether recruitment includes communications/interactions between study staff and potential participants either in person or online. *Submit a copy of all recruitment materials.*
No recruitment necessary. All students in class take the pre and post survey

d. Consent process including how information is presented to participants, etc.
Initially, the non-identified data was collected for purposes other than this proposed research project. However, it was deemed important to examine this data as part of an evaluation of the Lecture and Lab Activity. Therefore, this research involves less than minimal risk to the participants. The data is not identifiable by semester, class, or specific student. There is no risk of a breach of confidentiality as there are no individual identifiers within this pre-existing data set. Since there are no identifiers, there is no way to identify private information and thus will not adversely affect the rights and welfare of the students. Therefore, it would not be feasible to obtain consent from every student in the dataset and doing so may increase the risk of being identified.

e. Research procedures and methodology
Initially, the non-identified data was collected for purposes other than this proposed research project. However, it was deemed important to examine this data as part of an evaluation of the Lecture and Lab Activity. Therefore, for this research study, the sample population were all students in the class and lab, none were excluded or targeted. Students were invited to complete the pre and post surveys, which were available through the Canvas course module. These surveys were not graded and had no bearing on their course grades. There is no risk of a breach of confidentiality as there are no individual identifiers within this data set. Since there are no identifiers, there is no way to identify private information and thus will not adversely affect the rights and welfare of the students.

f. Anticipated time per study exercise/activity and total time if participants complete all study activities.
Part of classroom requirement. Labs involve 2 hours per week per semester. Pre and post exam requires approximately 20 minutes each.

g. Location of the research activities.
In classroom lectures, in Lab (Shelby 0317) and distance students online.

h. Costs to and compensation for participants? If participants will be compensated describe the amount, type, and process to distribute.
Zero

i. Non-AU locations, site, institutions. *Submit a copy of agreements/IRB approvals.*
No other sites

j. Describe how results of this study will be used (presentation? publication? thesis? dissertation?)
Used to support a dissertation

k. Additional relevant information.

Click or tap here to enter text.

Revised 09/13/2023

5. Waivers

Check applicable walvers and describe how the project meets the criteria for the waiver.

☒ Waiver of Consent (Including existing de-identified data)

☐ Waiver of Documentation of Consent (Use of Information Letter, rather than consent form requiring signatures)

Waiver of Parental Permission (In Alabama, 18 years-olds may be considered adults for research purposes)
https://sites.auburn.edu/admin/orc/irb/IRB 1 Exempt and Expedited/11-113 MR 1104 Hinton Renewal 2021-1.pdf

a. Provide the rationale for the waiver request.

Initially, the de-identified data was collected for purposes other than this proposed research project. However, it was deemed important to examine this data as part of an evaluation of the Lecture and Lab Activity. Therefore, this research involves less than minimal risk to the participants. The data is not identifiable by semester, class, or specific student. There is no risk of a breach of confidentiality as there are no individual identifiers within this existing data set. Since there are no identifiers, there is no way to identify private information and thus will not adversely affect the rights and welfare of the students. Therefore, it would not be feasible to obtain consent from every student in the dataset and doing so may increase the risk of being identified.

6. Describe the process to select participants/data/specimens. If applicable, include gender, race, and ethnicity of the participant population.

All students of the course. Survey is on Canvas, existing data.

7. Risks and Benefits

7a. Risks - Describe why none of the research procedures would cause a participant either physical or psychological discomfort or be perceived as discomfort above and beyond what the person would experience in daily life (minimal risk).

The pre and post class quiz has no impact on student grades. Student identity is not easily determined nor necessary .

7b. Benefits – Describe whether participants will benefit directly from participating in the study. If yes, describe the benefit. And, describe generalizable benefits resulting from the study.

No benefit

8. Describe the provisions to maintain confidentiality of data, including collection, transmission, and storage. Identify platforms used to collect and store study data. *For EXEMPT research, the AU IRB recommends AU BOX or using an AU issued and encrypted device. If a data collection form will be used, submit a copy.*

Data is stored in a secure Box folder. Names will be excluded from data for analysis and presentation.

a. If applicable, submit a copy of the data management plan or data use agreement.

9. Describe the provisions included in the research to protect the privacy interests of participants (e.g., others will not overhear conversations with potential participants, individuals will not be publicly identified or embarrassed).

Names are not relevant to the research. Names will be removed from analysis and findings.

10. Does this research include purchase(s) that involve technology hardware, software or online services?

☐ YES ☒ NO

If YES:

A. Provide the name of the product Click or tap here to enter text.
and the manufacturer of the product Click or tap here to enter text.

B. Briefly describe use of the product in the proposed human subject's research.
Click or tap here to enter text.

C. To ensure compliance with AU's Electronic and Information Technology Accessibility Policy, contact AU IT Vendor Vetting team at vetting@auburn.edu to learn the vendor registration process (prior to completing the purchase).

D. Include a copy of the documentation of the approval from AU Vetting with the revised submission.

11. Additional Information and/or attachments.

In the space below, provide any additional information you believe may help the IRB review of the proposed research. If attachments are included, list the attachments below. Attachments may include recruitment materials, consent documents, site permissions, IRB approvals from other institutions, data use agreements, data collection form, CITI training documentation, etc.

Click or tap here to enter text.

Required Signatures *(If a student PI is identified in item 1.a, the EXEMPT application must be re-signed and updated at every revision by the student PI and faculty advisor. The signature of the department head is required only on the initial submission of the EXEMPT application, regardless of PI. Staff and faculty PI submissions require the PI signature on all version, the department head signature on the original submission)*

Signature of Principal Investigator: Tom Devall Date: 05/24/2024

Signature of Faculty Advisor (if applicable): Maria M. Witte Date: 05/24/2024

Signature of Dept. Head: ____________________ Date: ____________

Version Date: May 24, 2024.