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The Impact of Collaborative and Simulation Sessions on Learning Lean Principles and Methods: A Multi-institutional Study*

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Industrial experts have implemented lean methods globally since the late 1970s in response to difficult economic conditions, as well as to compete in an increasingly global and difficult marketplace. The application of lean methods has been used to eliminate non-value added activities from business and manufacturing operations. By eliminating non-value added activities, organizations have been able to reduce costs, improve process flows, and increase value for customers. The popularity and benefits of lean methods have led to a demand for an engineering curriculum that includes lean principles and methods. Engineering student learners often do not have experience in manufacturing operations at the point in which they are introduced to lean principles and methods in their studies, thus selecting appropriate teaching methods is important in ensuring that students develop a working knowledge of how to apply lean tools. Previous research has demonstrated the importance of learner perceptions specifically, the role of self-efficacy beliefs and attitudes in motivation and in academic performance. Moreover, researchers have found that the use of collaborative activities and simulation can positively impact learning. However, few previous studies have reported on the impact of interactive sessions on learner perceptions, including self-efficacy beliefs and attitudes, and the possible impact of these effects on learning. This study sets out to examine the impact of self-efficacy beliefs and attitudes, resulting from the use of collaborative and simulation sessions on the learning of lean principles and methods. Participants in this study were undergraduate students, primarily engineering students, from three universities. Data were analyzed using paired t-tests. Based on the analyses, it was found that the sequencing of sessions was an important variable. The findings also suggest that the use of collaborative and simulation sessions has a positive impact on learner self-efficacy and on some learner attitudes.

Keywords: lean manufacturing; collaborative learning; simulation; self-efficacy beliefs; learner attitudes

1. Introduction

Many improvement techniques and tools have been introduced to help industrial experts reduce costs, improve process flow, and meet customer expectations. Lean or lean manufacturing is one method that has positively impacted industrial organizations over the last decade. The benefits of the application of lean principles and methods have been documented, not just in manufacturing, but also in the service sector. For example, Cookson *et al.* [1] demonstrated that one lean tool, Value Stream Mapping (VSM) can be used to identify waste and to generate ideas for improvement within a heathcare setting. Similarly, Wojtys *et al.* [2] showed that lean tools were used to improve the patient scheduling processes in an outpatient sports medicine clinic. The industrial engineer is focused on using scientific principles to design, manufacture, and improve systems. As identified by Zandin [3], 'the nature of the work of industrial engineers is to ensure that all goods and services are produced and provided at the right time, right cost, and with the right quality.' In today's global marketplace, industrial engineers must be able to apply both lean principles and lean methods to create more efficient and effective processes in both the manufacturing and service sector.

Even though lean manufacturing has been around since the early 1980s, many companies have failed in efforts to transform to a lean organization [4, 5]. One factor potentially leading to lean transformation failures may be the lack of clear targets or direction, stemming in part from organizational leaders and engineers being unable to articulate the advantages of such a transformation. The failure rate of lean transformations is estimated to be as high as 70–98%, based on the Association for Operation Management (APICS), a non-profit international education organization [6]. Rubrich [7] found that only 5% of organizations have fully implemented lean manufacturing. Inadequate training and lack of awareness of lean principles and methods [8] can result in long learning periods and lean transformation failure. Lean manufacturing, just like any other continuous improvement method, requires not only a deep understanding of the principles and methods of lean manufacturing, but also the ability to adapt what has been learned to a given situation. Since lean methods are not stan-

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dardized, training and teaching lean methods to learners, particularly those learners who do not have work experience, can be challenging.

Dukovska-Popovska, Hoven-Madsen, and Nielsen stated, 'The challenge, when teaching students, is to create a context so that they can imagine and understand why lean philosophy is important and how it can work. On the other hand, when teaching employees/practitioners, the challenge is to translate the Lean thinking into their own context and facilitate their learning process through the different issues of Lean thinking' [9, p. 1]. Lean manufacturing implementations often incorporate a number of methods, such as value stream mapping, standardized work, Kaizen, Kanban, Visual control, 5S, and Poka-Yoke. Lean teaching and training must provide learners with an understanding of lean principles and methods, as well as with practice in applying lean methods.

One reason that many trainers and educators have attempted to include non-traditional teaching methods in courses and workshops is the hope that these teaching methods will improve learning and help learners gain experience in applying what they have learned to real-world situations/environments. Even though traditional teaching methods are well-established and familiar to most learners, researchers have identified certain benefits of using non-traditional teaching methods over traditional teaching methods. For example, Deutsch [10] and Johnson and Johnson [11] proposed that cooperative learning activities provide positive interdependence among learners. Cooperative and collaborative learning have similar definitions. Harasim [12] defined collaborative learning as group learning, which encourages learners to work together on academic tasks. Collaborative teaching methods differ from traditional teaching methods where the instructor is the sole source of knowledge and skills. Researchers have found that cooperative learning not only improves learner abilities to reach learning goals, but also helps learners understand the importance of teamwork. Similarly, Johnson and Johnson [11] found cooperative learning improved learning outcome achievement, as well as learner motivation, classroom socialization, confidence, and attitudes. Hinde and Kovac [13] showed that learners received higher scores than learners in traditional classes when active learning methods were used. Active learning can be defined as 'any instructional method that engages learners in the learning process' [13, p. 1]. Other researchers have studied the differences between traditional and non-traditional teaching methods on learning. Hake [14] compared learning outcomes in an introductory physics course between two classroom techniques (lecture based and interactive-engagement methods). Over 6500 learners enrolled in 62 introductory physics courses participated. Data were collected from high schools, colleges, and universities. During the study, learners were asked to complete surveys using the original Halloun–Hestenes Mechanics Diagnostic test (MD), Force Concept Inventory (FCI), and problem-solving mechanical baseline test. Both MD and FCI were used to evaluate student understanding of the basic concepts of mechanics. The researchers found that classrooms using interactive-engagement methods improved problem-solving ability and increased learning of mechanic concepts compared with other techniques. Dempsey *et al.* [15] conducted a study where the use of simulations and games was observed to improve learning in preschools, K-12 classrooms, universities, military settings, and business domains. Similarly, Akinsola and Animasahun [16] explored the effect of using simulations for teaching mathematics in secondary schools. The researchers applied two teaching methods to test groups: a traditional teaching method and simulation. The results indicated that simulation improved learner performance and attitudes toward mathematics, more than the traditional teaching methods.

Studies indicate that the use of non-traditional teaching methods, such as simulation and collaborative learning activities, are being used more frequently in teaching lean manufacturing principles and methods, particularly in training targeted at industrial workers. For example, some universities, e.g., Massachusetts Institute of Technology, Ohio University, and the University of Kentucky, have developed and used simulations to teach and train workers in lean principles and methods. Similarly, Verma [17] reported survey results from the shipbuilding and repair industry, suggesting that at least 17 simulations have been used in lean manufacturing training programs.

Many consulting organizations have used non-traditional teaching techniques, e.g., simulations, games, collaborative learning activities, and hands-on exercises or activities as part of training sessions, with great success. For example, The Lean Enterprise Institute (LEI) was established to facilitate activities related to lean education and training in 1997. The LEI has about 60 university schools around the world, e.g., Arizona State University, Indiana State University, University of Dayton, and The University of Warwick (UK). Studies have indicated that the use of non-traditional teaching techniques have a direct positive effect on lean learning. Recent studies also provide some support to indicate that the use of these teaching techniques also increases learner self-efficacy beliefs and improves learner attitudes. High levels of self-efficacy beliefs and positive attitudes have been shown to have a significant impact on learner performance and achievement [18–21] in other domains. Previous reseach findings on self-efficacy beliefs and attitudes, as they relate to learning, are described next.

1.1 Self-efficacy beliefs

Self-efficacy beliefs are an important factor to consider in improving learning performance and outcomes. Bandura [22] proposed the concept of self-efficacy beliefs, which refers to a personal belief that one has the capability to learn or perform a particular behavior to complete a task and achieve a desired outcome. Bandura specifically defined self-efficacy beliefs as, 'people's judgments of their capabilities to organize and execute a course of action required to attain designated types of performance' [22, p. 391]. Self-efficacy reflects a belief about whether an individual can complete a specific task. People with a high level of self-efficacy not only believe that they can complete a task, but they also work harder and show more persistence, leading to greater success. In contrast, people with low levels of self-efficacy do not believe that they can complete a task and try to avoid the task. The level of self-efficacy beliefs has an impact on the level of effort required and the amount of time required when confronting a task and/or obstacle [23]. Different beliefs related to individual abilities and/or levels of self-efficacy may influence people's ability to work.

Bandura [24] stated that people learn not only through experiences but also from observing others perform and observing outcomes. People then copy the observed behaviors. Self-efficacy beliefs have been found to enhance an individual's ability to face difficulties and to sustain efforts to accomplish a task successfully. Bandura pointed out four experience sources that can affect self-efficacy beliefs: mastery experience, vicarious experience, verbal or social persuasion, and physiological factors. Mastery experience refers to an individual's previous task experiences and performance. The level of self-efficacy can decrease or increase, depending on individual past experience. Likewise, people who fail in similar task will have lower levels of self-efficacy, which will affect the learner's ability to succeed at new tasks.

Vicarious experience results from observing others experience success or failure in a similar task or situation. The level of self-efficacy beliefs can decrease or increase depending on observations of others. Bandura stated, 'Seeing people similar to oneself succeed by sustained effort raises observers' beliefs that they too possess the capabilities to master comparable activities and to succeed' [25, p. 71]. The level of self-efficacy may also increase or decrease depending on encouragement and/or discouragement received from other people. For example, people will have a high level of self-efficacy when receiving encouragement or positive feedback or input from trusted or influential others. On the other hand, negative feedback decreases the level of self-efficacy. Finally, the level of self-efficacy is also influenced by physiological factors (e.g., moods, emotions, physical reactions, and stress). For example, people experiencing high stress may exhibit decreased levels of self-efficacy, which in turn can result in task failure.

The concept of self-efficacy has been shown to influence motivation, task performance, and individual goal setting. One recent study by Lunenburg [21] showed that high levels of self-efficacy are strongly linked to learning, task performance, and individual goal setting. Lunenburg stated that the reason that self-efficacy beliefs have a significant impact on learning, motivation, and performance is that people try to learn or do a task when people believe or think they can successfully accomplish the task. Further, people with a high level of self-efficacy tend to learn more from training and also tend to use what they have learned to enhance job performance.

Many previous studies have revealed that self-efficacy beliefs are related to learning outcomes. For example, Yildirim *et al.* [26] studied the relationship between learner outcomes and self-efficacy beliefs. Subjects were 50 sophomores and 17 seniors who were studying industrial engineering at the University of Pittsburgh. Three to four participants were given Model Eliciting Activities (MEA) to solve. Participants were required to solve specific MEA problems and rate how well they believed they did on each question. The goal was to analyze the level of modeling and problem-solving skills, as well as to measure the self-efficacy beliefs of participants. The research results showed that a significant correlation existed between self-efficacy beliefs and performance. As part of the study, anonymous peer reviews were automatically received for each learner's homework and sent back to the student through a system, called a research-networked portfolio system. Learners were required to revise homework based on the peer reviews and complete questionnaires through the same system. The research results supported Bandura's [24] proposition that self-efficacy beliefs can develop through social persuasion. The results showed that learners with high levels of self-efficacy beliefs applied higher-level learning strategies, such as elaboration and critical thinking, compared with students with lower levels of self-efficacy beliefs.

Similarly, in 2009, Isman and Celikli [20] studied the impact of self-efficacy beliefs and analyzed learner beliefs towards the use of computer technology. The study included 70 undergraduate students from the Eastern Mediterranean University's Faculty of Education. Approximately 36 participants were from the English Language Teaching Department, and 34 participants were from the Turkish Language Teaching Department. Survey questions were used to measure individual self-efficacy levels. Data on past experience, gender, and department were also collected. The researchers found that the number of years participants had used a computer had an impact on self-efficacy beliefs. Specifically, the study showed that participants who had experience using a computer for four years or more had higher confidence in their computer skills compared with a group of participants who had used a computer for fewer than four years. Adeyemo [19] studied the influence of emotional intelligence on academic self-efficacy beliefs and on the achievements of university students. A total of 300 participants participated in the study. Participants were asked to complete a questionnaire using the Academic Confidence Scale (ACS) developed by Sanders and Sander [27]. The results showed a significant, positive relationship between academic achievement and academic self-efficacy beliefs.

Mahyuddin *et al.* [18] explored the relationship between self-efficacy beliefs and English language acquisition. A total of 1146 participants from eight secondary schools participated in this study. The participants came from different countries, including Malaysia, China, and India. The objectives of the study were focused on four areas:

(1) measuring the level of self-efficacy beliefs related to knowledge of the English language;
(2) measuring the difference in the level of self-efficacy beliefs between males and females;
(3) measuring the difference in the level of self-efficacy beliefs between urban and rural schools; and
(4) measuring the relationship between self-efficacy beliefs and English language acquisition.

The self-efficacy beliefs scale developed by Bandura [28] and Kim and Park [29] were used to measure participant self-efficacy beliefs. The results showed that about 55% of participants had high self-efficacy beliefs, and 49% had low self-efficacy beliefs related to knowledge of the English language. A total of 44% of those people with low self-efficacy beliefs, related to knowledge of the English language, believed that English was difficult for them, which resulted in a lower motivation to learn. Moreover, researchers found that there was a relationship between self-efficacy beliefs and learning achievement. The results indicated that participants with higher levels of self-efficacy beliefs demonstrated better performance when compared with those with lower levels of self-efficacy beliefs.

Lorsbach and Jinks [30] studied the impact of self-efficacy beliefs on learning environments. The researchers concluded that individual self-efficacy beliefs regarding academic performance are an important key to improving learning environments and to improving learner outcomes. The authors suggested that the concept of academic self-efficacy beliefs aids in understanding what is happening in the classroom and helps educators, instructors, and students improve the learning environment. Zimmerman and Kitsantas [31] studied whether learner self-efficacy beliefs affected homework practices and grade point average. A total of 179 high school girls participated in the study. A survey was administered during a regular class period at the beginning of the second quarter in the school year. The survey included 86 items in four areas: personal data questions, homework survey, self-efficacy beliefs, and perceived responsibility for learning. The results indicated that homework practices significantly predicted learner self-efficacy beliefs, learning outcomes, and perceptions of responsibility for learning. Learner self-efficacy beliefs and perceptions of responsibility for learning were found to play an important role in homework practices and GPA.

To date, many researchers have found that individual self-efficacy beliefs and attitudes are significant, influential factors in academic achievement and work performance. Moreover, previous studies have identified the importance of learner attitudes in learning achievement and performance. Improved learner attitudes should have a positive influence on learning. The role of attitudes on learning, based on previous research, is discussed next.

1.2 Attitudes

Studies of learner attitudes, specifically towards simulation, are limited. Attitudes are an important factor in educational research and can help researchers to understand and predict reactions to objects or changes [32]. Gardner [33, p. 9] defined an individual's attitude as 'an evaluative reaction to some referent, inferred on the basis of the individual's beliefs or opinions about the referents.' Two attitudes explored in the literature related to learning are motivation and enjoyment.

According to Mullins [34] motivation is 'the driving force within individuals by which they attempt to achieve some goal in order to fulfill some need or expectation.' Bomia *et al.* [35, p. 1] defined motivation as, 'a student's willingness, need, desire, and compulsion to participate in, and be successful in, the learning process.' Motivation has been found to be positively correlated with learning skills and academic achievement. Three types of motivation defined in the literature are intrinsic goal orientation, extrinsic goal orientation, and task value. Intrinsic goal orientation refers to the extent to which an individual takes on a task because the task is challenging or interesting. Extrinsic goal orientation refers to the extent to which an individual takes on a task because the task is connected with some external condition such as a course grade that is motivating. Task value refers to the extent to which an individual engages in a task because the task is seen as important.

Many studies have found significant relationships between learner attitudes and learning. For example, Luckie *et al.* [36] argued that improvement in attitudes towards a learning experience leads to higher achievement. Prokop *et al.* [37] studied the relationship between student knowledge and attitudes toward biotechnology. A total of 378 students participated in the study. Students completed two surveys, including a biotechnology attitude questionnaire and a biotechnology knowledge questionnaire. The results showed a significant, positive correlation between attitudes and the level of individual knowledge. Similarly, Gottfried [38] examined the relationship between intrinsic motivation and academic achievement. The research results showed that intrinsic motivation was positively related to academic achievement and to IQ. The results indicated that a decrease in intrinsic motivation might result in a significant decrease in academic achievement.

Other studies have found a significant relationship between knowledge, attitudes, and achievement [39–40]. Depaolo and McLaren [41] investigated the relationship between learner attitudes and performance in statistics and calculus. The study included 229 participants. Data were collected from individual records, performance on in-class exams, and three surveys. Surveys were used to measure student experiences with math and current attitudes toward math and calculus. The results found that individuals developed more positive attitudes during the class; however, learners had less positive attitudes towards calculus than statistics. The study results also indicated that learners who earned lower exam scores showed negative attitudes toward statistics and calculus. Depaola and McLaren also found that learners who did not have a background in calculus did poorly on the exam and held strong negative attitudes toward calculus.

Similarly, Lin *et al.* [42] studied the influence of extrinsic and intrinsic motivation on learning. A total of 650 participants were recruited from college students in 13 classes, including biology and psychology at the University of Michigan, Alma College, Washtenaw Community College, Eastern Michigan University, and Keimyung University in Korea. The scores of both intrinsic and extrinsic motivation scales were divided into low, medium, and high levels. Items on the Motivated Strategies for Learning Questionnaire (MSLQ) were scored using a five-point Likert scale. The results indicated that learners with high levels of intrinsic motivation and medium levels of extrinsic motivation received higher mean course grades than learners with either low or high extrinsic motivation. Another study by Eccles *et al.* [43] highlighted the importance of learner task value as a positive predictor of intentions and decisions to take mathematics and English classes continuously.

Individual enjoyment has also been associated with higher degrees of motivation, learning, and learning outcome achievement. Blunsdon *et al.* [44] found that enjoyment had a positive impact on improving learner perceptions and increasing learning outcome achievement. In contrast, Rieber and Noah [45] studied the impact of game-like activities on adult learning during a computer-based simulation. The research found no correlation between enjoyment and learning outcome achievement. The study revealed that the fun and enjoyment resulting from playing the game disrupted student learning.

The purpose of this study was to explore the effects of the use of collaborative and simulation teaching techniques on self-efficacy beliefs and attitudes. The investigation focused on the use of collaborative and simulation for teaching lean principles and methods in the higher education classroom. Collaborative sessions consisted of lectures and some type of in-class activity. Simulation sessions were live simulations. Two research hypotheses were developed: 1) collaborative and/or simulation sessions do not affect self-efficacy beliefs: 2) collaborative and/or simulation sessions do not affect learner motivation or enjoyment. The research methods used to test these hypotheses are described next.

2. Methods

2.1 Participants

One hundred and fifty-five undergraduate students from three universities (University of Pittsburgh, Worcester Polytechnic Institute, and Oakland University's Pawley Lean Institute) participated in the study. A recruitment letter or e-mail was sent to instructors who planned to teach lean manufacturing systems or related courses on lean principles and methods. Hardcopy surveys and consent forms were sent by post to instructors, after the instructors agreed to participate in the study.

2.2 Lean or related lean course description

The instructors at all three universities used both collaborative and simulation sessions in these courses. The collaborative sessions included both traditional teaching methods (lectures, PowerPoint presentations, and case studies) and in-class activities. The three universities structured learning activities in different sequences. Learners from the University of Pittsburgh studied the topics first using simulation sessions, followed by collaborative sessions. Worcester Polytechnic Institute and Oakland University's Pawley Lean Institute led collaborative sessions first, followed by simulation sessions. Three in-class activities and two different simulation activities were used in these courses as detailed in Table 1. More detailed information on the two simulations used by the three participating universities is provided next.

The TimeWise Simulation, used by two of the universities, is a simulated clock assembly line. Role-playing provides an opportunity for learners to apply lean methods in a physical clock assembly environment. The TimeWise Simulation allows learners to experience the differences between traditional and lean manufacturing approaches. Learners are given a specific role in the simulated clock assembly line, such as assembly operator or support personnel. Participants work to assemble two different clock models: a blue clock and a black clock. The TimeWise Simulation is run in four rounds. Participants experience traditional manufacturing processes in the first round and learn to apply lean manufacturing principles and methods during the second, third, and fourth rounds. Each round takes approximately 15 minutes to complete and is facilitated by the instructor. The TimeWise Simulation allows participants the opportunity to learn by doing and gives participants the ability to see how lean principles and methods can be applied. Several lean principles and methods are presented at various points in the simulation, including pull production, Poka-Yoke, 5S, and visual workplace techniques.

Oakland University's Pawley Lean Institute offers a lean class for undergraduates, which meets for approximately three hours, once a week. A simulation, called the Mouse Trap simulation, is used to demonstrate the differences between mass and batch production. The simulation uses the board game, Mouse Trap, as the basic production process. Following a lecture on lean principles, participants are challenged to create an improved production system. Three to five learners work together in a group. The Mouse Trap simulation takes approximately three hours to complete and is run in three rounds. In each round, learners are allowed to change only two things. The goal is to meet specific production objectives. The Mouse Trap simulation focuses on two lean methods: standardization and pull production. The simulation also introduces the plan/do/check/act (PDCA) cycle for improvement. The procedures and instruments used to test the two hypotheses developed for this study are described next.

2.3 Procedures and instruments

Two sets of surveys were distributed to participants to measure self-efficacy beliefs and four different attitude constructs. The survey items for each construct were based on the Motivated Strategies for Learning Questionnaire (MSLQ) [46] and [47]. The four attitude constructs included on the survey were intrinsic goal orientation, extrinsic goal orientation, task value, and enjoyment. Each survey consisted of 22 items: six items to measure self-efficacy beliefs, four items to measure intrinsic goal orientation, four items to measure extrinsic goal orientation, four items to measure task value, and four items to measure enjoyment. Participants

Table 1. Description of collaborative and simulation activities for each participating university

University	Collaborative activity	Simulation activity
University of Pittsburgh	*Penny Fab*: This activity provides participants an understanding of the concepts of work in process, throughput, cycle time, and inventory in a penny production line. Participants work together using four workstations sequenced for producing pennies. Each workstation consists of a single machine, including a punch press station, a two-sided stamp station, rim station, and cleaning station.	TimeWise Simulation
Worcester Polytechnic Institute	*Dice Game*: This activity explores the differences between push and pull manufacturing systems using dice. Five to seven participants work together in sequence. The activity starts with a traditional manufacturing system and then changes to a pull manufacturing system.	TimeWise Simulation
Oakland University's Pawley Lean Institute	*Paper Cup Game*: This activity illustrates pull and other lean concepts. Participants work together in teams to assemble paper cups and lids into a tray. Four stations are set up to put four cups in a tray, place red dots on the cups, put lids on the cups, and put straws in the cups. The activity starts as a push manufacturing system in which participants are told to process as many cups as possible. The manufacturing system changes from push to pull, where participants are allowed to work only when the work queue is empty.	Mouse Trap simulation

responded to each item using a 5-point Likert scale (1 = Strongly disagree; 2 = Disagree; 3 = Undecided; 4 = Agree; and 5 = Strongly agree). The survey was administered at each university twice. The surveys were administered to measure learner self-efficacy beliefs and attitudes both before and after collaborative sessions and simulation sessions. The three universities administered the surveys at different times, depending on the course schedule. Table 2 lists the survey items used to measure learner self-efficacy beliefs. Table 3 lists the survey items used to measure learner attitudes. The survey data were analyzed. Survey data are summarized and results of these analyses are presented next.

3. Results

SPSS IBM 19.0 was used to complete all analyses. Cronbach's alpha for each set of survey items was calculated to check the internal reliability of each construct. The Cronbach's alpha coefficients for each construct are summarized in Table 4. All constructs had a Cronbach's alpha coefficient greater than 0.65, and most constructs were greater than 0.75. Nunnally [48] and Garson [49] stated that a Cronbach's alpha coefficient greater than 0.7 is considered satisfactory, whereas a coefficient of 0.5 or above is considered acceptable. For this reason, the constructs for this study were considered to be

Table 2. Learner self-efficacy beliefs survey items

Items
• As a result of [type of session]*, I believe that I will be able to respond to exam questions on lean manufacturing. • The [type of session]* increased my confidence in my own understanding of lean manufacturing principles. • I am certain I understand the most difficult principles used in the [type of session]. • As a result of [type of session]*, I have no doubt about my capability to do well on lean manufacturing assignments. • As a result of [type of session]*, I can now explain to my friends what I have learned about lean manufacturing. • I am certain I can master the skills being taught in the [type of session]*.

* The phrase, 'type of session,' was replaced with either 'collaborative session' or 'simulation session.'

Table 3. Learner attitudes survey items

Attitude	**Items**
Intrinsic goal orientation	• I prefer [type of session] that are challenging so I can learn new things. • I prefer [type of session] that arouses my curiosity, even if they are difficult. • I prefer [type of session] that I will learn something from even if they require more work. • I prefer [type of session] that I can learn something from even if they do not guarantee a good grade.
Extrinsic goal orientation	• Learning from [type of session] helps prepare me for tests. • Learning from [type of session] helps me get good grade on tests. • I participate in [type of session] because I am supposed to. • I prefer [type of session] because I am sure I can do them.
Task value	• As a result of [type of session], I believe that I will able to use what I have learned in other courses. • It is important for me to learn what is taught in [type of session]. • I think that what I have learned from [type of session] is useful for me to know. • As a result of [type of session], I believe that I can apply what I have learned to real-world problems.
Enjoyment	• I enjoy participating in [type of session]. • I feel that time flies when I participate in [type of session]. • After finishing [type of session], I look forward to the next class. • I would like to spend more time on [type of session].

* The phrase, 'type of session,' was replaced with either 'collaborative session' or 'simulation session.'

Table 4. Internal reliability for survey constructs

Survey construct	**Number of items**	**Cronbach's alpha**
Lean self-efficacy beliefs after collaborative sessions	6	0.87
Lean self-efficacy beliefs after simulation sessions	6	0.86
Intrinsic goal orientation after collaborative sessions	4	0.76
Intrinsic goal orientation after simulation sessions	4	0.63
Extrinsic goal orientation after collaborative sessions	4	0.75
Extrinsic goal orientation after simulation sessions	4	0.73
Task value after collaborative sessions	4	0.73
Task value after simulation sessions	4	0.88
Enjoyment after collaborative sessions	4	0.86
Enjoyment after simulation sessions	4	0.89

Table 5. Mean scores and paired t-test results for self-efficacy after participating in collaborative and simulation sessions

	n	Mean 1st	Mean 2nd	Paired t-test statistic	*p*-value
University of Pittsburgh	46	4.15^{s}	3.89^{c}	–2.81	**0.007**
Worcester Polytechnic Institute	18	3.60^{c}	3.91^{s}	–2.13	**0.048**
Oakland University's Pawley Lean Institute	18	4.44^{c}	4.51^{s}	–0.68	0.505

Note: 'c' refers to collaborative sessions and 's' refers to simulation sessions.

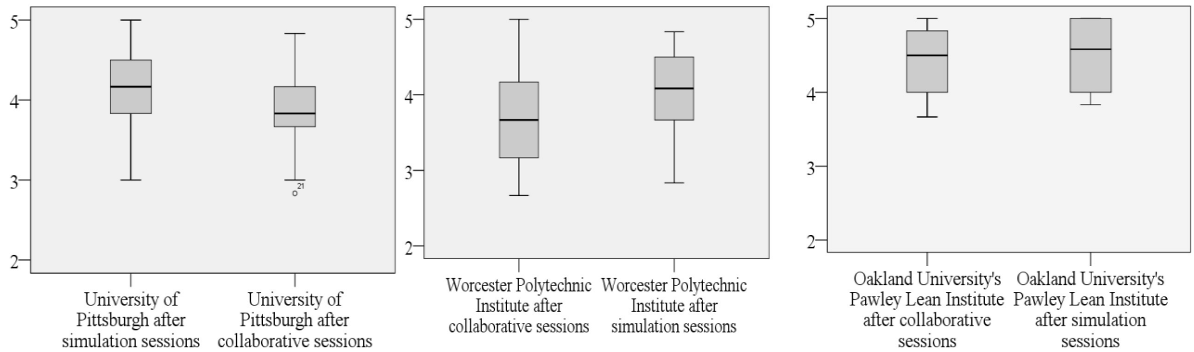

Fig. 1. Box plots comparing self-efficacy beliefs following collaborative and simulation sessions for each university.

reliable. Q–Q plots were created and reviewed to determine whether or not the self-efficacy and attitudes data were normally distributed. Based on these plots, the data appeared to be normally distributed. Paired t-tests were used to identify differences in learner self-efficacy beliefs and/or learner attitudes (intrinsic goal orientation, extrinsic goal orientation, task value, and enjoyment) following the use of collaborative and simulation sessions. A p-value of 0.05 was used to identify statistically significant relationships.

As shown in Table 5, significant differences in self-efficacy beliefs following the use of collaborative and simulation sessions were observed for learners at the University of Pittsburgh and Worcester Polytechnic Institute. No statistically significant differences were found in learner self-efficacy beliefs for participants from Oakland University's Pawley Lean Institute. Learners from Worcester Polytechnic Institute and Oakland University's Pawley Lean Institute showed improvement in lean self-efficacy beliefs, after participating in simulation sessions. Figure 1 graphically summarizes survey results for each university.

As shown in Table 6, only participants from Worcester Polytechnic Institute exhibited statistically significant improvements in intrinsic motivation after having first participated in collaborative sessions, followed by simulation sessions. Figure 2 graphically summarizes these results for each university. As shown in Table 7, significant differences in learner extrinsic goal orientation were found for participants from all three universities. For universities where collaborative sessions were used first, followed by simulation sessions, the findings revealed that learner extrinsic motivation increased after participating in simulation sessions. On the other hand, for the University of Pittsburgh, the

Table 6. Mean scores and paired t-test results for intrinsic goal orientation after participating in collaborative and simulation sessions

	n	Mean Survey 1	Mean Survey 2	Paired t-tests statistic	Sig. (2-tailed)
University of Pittsburgh	46	3.84^{s}	3.86^{c}	0.25	0.802
Worcester Polytechnic Institute	18	3.70^{c}	3.99^{s}	–2.76	**0.013**
Oakland University's Pawley Lean Institute	18	4.38^{c}	4.33^{s}	0.23	0.820

Note: 'c' refers to collaborative sessions and 's' refers to simulation sessions.

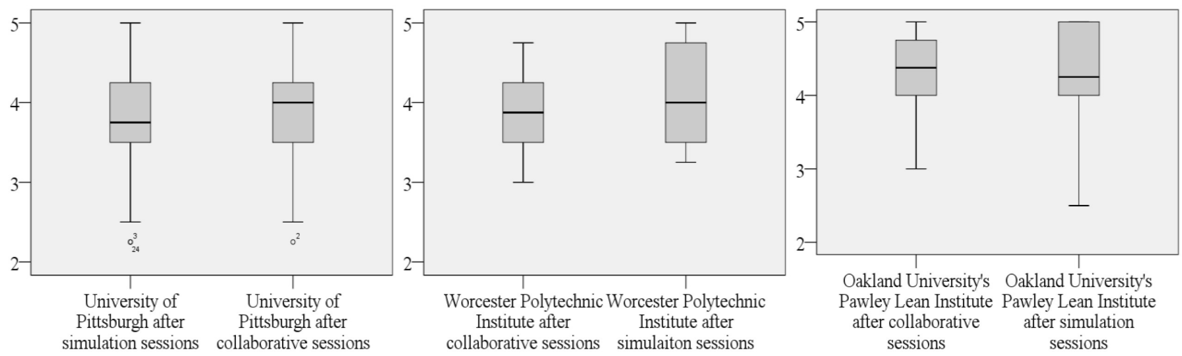

Fig. 2. Box plots comparing learner intrinsic goal orientation following collaborative and simulation sessions for each university.

Table 7. Mean scores and paired t-test results for extrinsic goal orientation after participating in collaborative and simulation session

	n	Mean: Survey 1	Mean: Survey 2	Paired t-tests statistic	Sig.
University of Pittsburgh	46	3.93^{s}	3.76^{c}	–2.20	**0.033**
Worcester Polytechnic Institute	18	3.86^{c}	4.28^{s}	–2.25	**0.017**
Oakland University's Pawley Lean Institute	18	3.80^{c}	4.15^{s}	–3.05	**0.007**

Note: 'c' refers to collaborative sessions and 's' refers to simulation sessions.

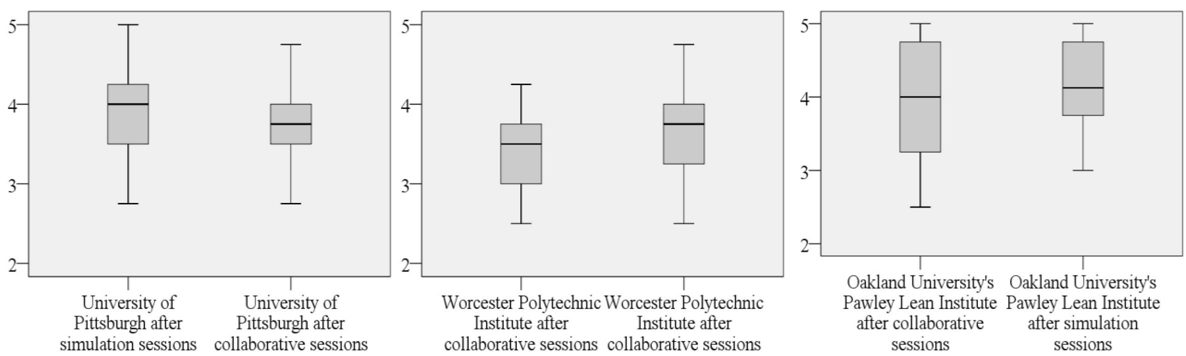

Fig. 3. Box plots comparing extrinsic goal orientation following collaborative and simulation sessions for each university.

Table 8. Mean scores and paired t-test results for task value after participating in collaborative and simulation sessions

	n	Mean: Survey 1	Mean: Survey 2	Paired t-tests statistic	Sig. (2-tailed)
University of Pittsburgh	46	4.23^{s}	4.42^{c}	–2.75	**0.009**
Worcester Polytechnic Institute	18	4.00^{c}	4.04^{s}	–0.36	0.725
Oakland University's Pawley Lean Institute	18	4.60^{c}	4.59^{s}	0.13	0.901

Note: 'c' refers to collaborative sessions and 's' refers to simulation sessions.

findings revealed that learner extrinsic motivation decreased after participating in collaborative sessions. Figure 3 graphically summarizes these results for each university. As shown in Table 8, the paired t-test results showed that only participants from the University of Pittsburgh experienced an increase in task value, having first participated in simulation sessions, followed by collaborative sessions. Figure 4 graphically summarizes these results, for each university. As shown in Table 9, the paired t-test results indicated no significant differences in learner enjoyment for participants from any of the three

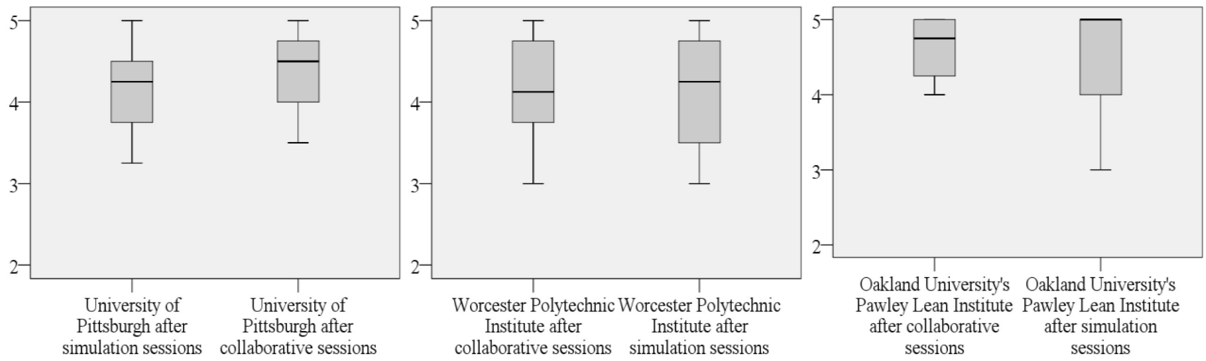

Fig. 4. Box plots comparing task value following collaborative and simulation sessions for each university.

Table 9. Mean scores and paired t-test results for enjoyment after participating in collaborative and simulation sessions

		Mean			
	n	**Survey 1**	**Survey 2**	**Paired t-tests statistic**	**Sig. (2-tailed)**
University of Pittsburgh	46	3.71^{s}	3.80^{c}	0.74	0.464
Worcester Polytechnic Institute	18	3.40^{c}	3.92^{s}	–1.84	0.084
Oakland University's Pawley Lean Institute	18	4.22^{c}	4.51^{s}	–1.41	0.176

Note: 'c' refers to collaborative sessions and 's' refers to simulation sessions.

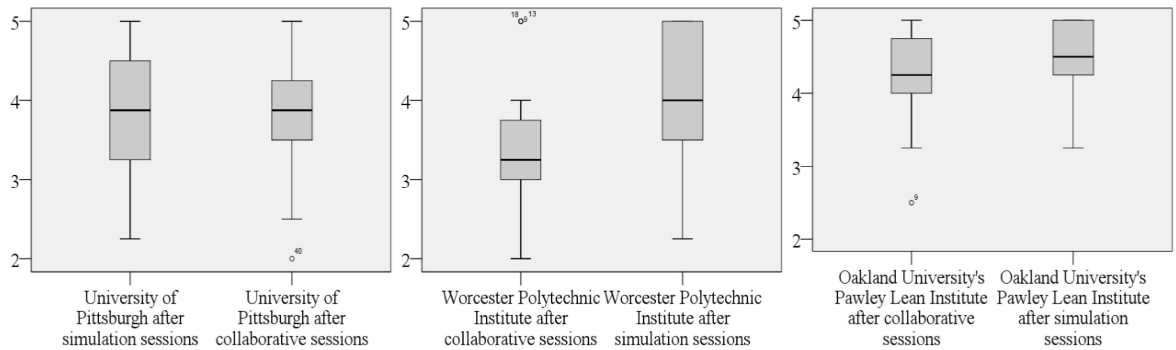

Fig. 5. Box plots comparing enjoyment following collaborative and simulation sessions for each university.

universities. Figure 5 graphically summarizes these results for each university. Table 10 summarizes the overall set of findings. Positive and significant relationships are depicted with a '+'; whereas, negative and non-significant relationships are depicted using a '–' or '0,' respectively.

4. Findings

This study investigated the impact of non-traditional teaching methods, both collaborative and simulation sessions, on learner self-efficacy beliefs and attitudes (intrinsic goal orientation, extrinsic goal orientation, task value, and enjoyment). Overall, the findings did provide some evidence to reject both null hypotheses that the use of collaborative and simulation sessions do not have an impact on learner self-efficacy beliefs or on some learner attitudes. It appears that the use of non-traditional methods did impact learner self-efficacy beliefs. There was also limited evidence that participation in non-traditional sessions impacted some learner attitudes. The implications of these research findings are discussed next.

The results from this study suggest that the sequencing of sessions (collaborative and simulation), when teaching lean principles and methods, has an influence on learner self-efficacy beliefs related to learning lean principles and methods. Specifically, learners at the universities where collaborative sessions were used first, followed by simulation sessions, either exhibited no change, or a positive increase in levels of lean self-efficacy beliefs. Previous research has not explored the role of the sequencing of different types of non-traditional teaching methods. These findings should be consid-

Table 10. Summary of research results

Research hypotheses	University	Relationship
Collaborative and/or simulation sessions do not affect lean self-efficacy beliefs.	University of Pittsburgh	–
	Worcester Polytechnic Institute	+
	Oakland University's Pawley Lean Institute	0
Collaborative and/or simulation sessions do not affect intrinsic goal orientation.	University of Pittsburgh	0
	Worcester Polytechnic Institute	+
	Oakland University's Pawley Lean Institute	0
Collaborative and/or simulation sessions do not affect extrinsic goal orientation.	University of Pittsburgh	–
	Worcester Polytechnic Institute	+
	Oakland University's Pawley Lean Institute	+
Collaborative and/or simulation sessions do not affect task value.	University of Pittsburgh	+
	Worcester Polytechnic Institute	0
	Oakland University's Pawley Lean Institute	0
Collaborative and/or simulation sessions do not affect enjoyment.	University of Pittsburgh	0
	Worcester Polytechnic Institute	0
	Oakland University's Pawley Lean Institute	0

ered in designing future studies of the relationship between non-traditional learning techniques and self-efficacy beliefs in other domains. It appears that learners are better served by being exposed to lean concepts initially with collaborative learning activities, followed by simulation sessions. It is possible that the simulation sessions are too complex in the initial phases of learning and that the collaborative learning sessions provide learners with the confidence they need to more fully explore concepts during the simulation sessions.

The results from the analyses of learner attitudes indicated that both collaborative sessions and simulation sessions aroused interest in learning lean principles and methods, based on the average values for all three university, with all four attitudes being above 3.5 and, in many cases, over 4.0 on the 5-point Likert scale, indicative of agreement with the survey items, which reflects positive experiences. Significant differences in extrinsic goal motivation were observed for all three universities. However, the effect of the sessions on extrinsic motivation was different, again depending on the sequencing of the sessions. Extrinsic motivation increased when learners were exposed to collaborative sessions first, followed by simulation sessions. Extrinsic motivation decreased at the University of Pittsburgh where simulation sessions were introduced first. Again, there was evidence that the sequence of teaching techniques impacted learner extrinsic motivation in learning lean principles and methods.

While no differences were found in enjoyment, despite differences in session type and sequence, learner enjoyment was moderately high for all three universities, following both types of sessions. It appears that learners found both types of sessions to be fun and enjoyable. It can be concluded that both collaborative sessions and simulation sessions result in enjoyable experiences for learners. These results are consistent with findings in other learning domains. For example, Rose [50] found that a board game, designed to promote student learning, improved student enjoyment for pharmacy students learning about metabolic pathway. These findings are important and make a strong contribution towards understanding approaches that can be used to improve learning, particularly in domains where the application of knowledge is important. There are, however, some limitations associated with the study, which will be described next.

5. Study limitations

First, data for this study were collected only after collaborative sessions and after simulation sessions were conducted. Future research in which learner perceptions are measured both prior to each type of session and following each type of session could provide a deeper understanding of the sequencing effects indicated by this study. In addition, data for this study were collected in natural settings, i.e. real classrooms. No steps were taken to control for differences in instructors, specific course content, or student capabilities. The findings cannot be broadly generalized and other factors, which were not measured, may have impacted the results. A final limitation is that only learner perceptions were measured. Academic achievement, related to the content of the collaborative and simulation sessions was not measured for this study, due to differences in the course-level learning outcomes. Future studies in which both academic achievement and learner perceptions are measured could provide additional insight for educators and help educators evaluate whether or not non-traditional teaching methods provide significant value, given the time investment required to develop and use collaborative and simulation sessions. Notwithstanding these limitations, the results of this research do have important implications. The research makes a distinct contribution to the body of knowledge on interactive learning techniques and to the practice of engineering education. The most significant contributions resulting from this study are summarized next.

6. Conclusions

The results of this study have direct implications for engineering educators. The findings of this research provide evidence that the use of collaborative sessions, followed by simulation sessions, is an effective means for improving learner self-efficacy beliefs, as well as positively impacting learner motivation. Overall these results add to the body of knowledge on the use of non-traditional teaching methods and support previous research that has indicated that such methods can be successfully used to supplement traditional teaching methods in the higher education classroom. These findings are also consistent with the practitioner literature that advocates for the use of these methods in providing lean training for industrial workers. The sequencing of non-traditional teaching methods appears to be important in determining whether or not learning perceptions are improved or unchanged. Intrinsic motivation, task value, and enjoyment were not uniformly impacted, based on the results of this study. These findings are not consistent with previous research findings in other domains and provide some evidence that additional research is needed to more fully characterize the impact of non-traditional teaching methods on these particular learning perceptions. Overall, however, the findings from this research seem to indicate that collaborative sessions and simulation sessions do provide a favorable learning environment and that both non-traditional teaching methods can be used to enhance the learning environment.

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