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Author(s)	McDermott, Olivia
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Designing online delivery of Lean education during COVID-19

Olivia McDermott

College of Science & Engineering, University of Galway, Galway, Ireland

Abstract

Purpose: This study describes how two organisations transitioned to teaching Lean online during and post Covid-19. The study aims to establish how Lean teaching and training can be designed and delivered effectively online without adverse effects on the student learning experience of Lean concepts.

Design Methodology/Approach. A case study approach was utilised to review the design, application and results of the transition to online Lean teaching and training. Qualitative and quantitative methods were deployed to assess the results.

Findings: Online Lean learning and application were assured via the design of practical problem-based teaching environments aided by utilising the virtual classroom as an obeya room and as a kaizen environment where students worked in teams. Students were enabled to learn and apply Lean tools practically and reflect on their learnings.

Practical Implications/Limitations. This study demonstrates that effective online design can ensure. Lean methods are understood without affecting the student's learning, classroom experience and grasp of concepts.

Originality/Value: This is one of the first studies on implementing Lean training and education online during COVID-19 under the lens of both a training provider and university education viewpoint. The changes validated best practices for virtual Lean education and training in the organisations under study, maintained post-COVID.

Keywords: Lean, Online education, training, COVID-19, virtual

1.0 Introduction

The digital era has encouraged the use of online technology in the education sector (Junus *et al.*, 2021). However, the Coronavirus Disease 19 (COVID-19) outbreak, resulting in social distancing rules and reduced face-to-face contact, has delayed or cancelled many types of classroom training. Due to the COVID-19 pandemic, most educational institutions, both universities and training organisations worldwide, have moved their teaching and training online to ensure uninterrupted learning continuity (Tortorella et al., 2021). The COVID-19 pandemic, however, was a gigantic challenge to education systems (Daniel, 2020). COVID-19 brought significant challenges in technology adoption in higher education and rethinking teaching practice (Alexander *et al.*, 2019).

The COVID-19 pandemic brought significant disruption to educational practices in all subject areas, particularly to Lean educators, who are the focus of this study. Before COVID-19, Lean education took place via classroom-based games, team activities and practical exercises by many Lean educators (Cudney *et al.*, 2011). Many studies have introduced game-based learning or gamification as important in learning, as in an ideal educational game setting, students learn how to solve complex problems.(Badurdeen *et al.*, 2010; Cudney *et al.*, 2011). Games can be defined in different ways as "*competitive exercises in which the objective is to win and players must apply subject matter or other relevant knowledge to advance in the exercise*" (Pastore and Falvo, 2010). Others have described "gamification" as a method to ensure active learning and participation (McDermott, 2021).

The problems within a game typically start easy and then progressively become more difficult as players' skills develop. In part, players are motivated to learn because learning is situated and occurs through a process of hypothesising, probing, and reflecting upon the simulated world within the game.

Within a physical classroom or training room, there is wall space for "paper" based mapping and brainstorming exercises with whiteboards and A3 display stands. This layout and space ensured that Lean education and training could be delivered to many students at a time in a practical and blended manner. Problem-and scenario-based learning is best suited for teaching about Lean manufacturing, as it promotes scenarios that assure learning (Badurdeen *et al.*, 2010). The two participants in this case study involved an Irish Lean training provider and an Irish university.

While the training provider is a private sector organisation that profits from Lean education, the university is a public service non-profit educator. The customers deprioritised internal and external training programs within the training providers' customer base with the advent of COVID-19. Uniquely within this training provider's customer base, the customers who utilised the provider's services for training were kept open by the Irish government, who deemed them essential, e.g. medical devices, food processing, and pharmaceuticals (Carswell, 2020). Similarly, the university moved education online, and thus, students still needed to be educated and learn about Lean.

Neither the training provider nor the university could meet the requirements above to train and educate in a non-socially distanced classroom. Therefore, to remain functional and maintain training commitments committed to customers and deliver lectures required by students, the decision was made to transfer training and lectures online.

Lean training is generally blended or classroom-based and can involve team-based activities, practical exercises, brainstorming and working on an in-company project; if applicable, this transition was not seamless (Homitz and Berge, 2008). Students and trainees work on problems and projects related to their workplace (if applicable) and solve hypothetical scenarios utilising Lean tools. In-person classroom interaction must be reproduced online to ensure effective learning (Cudney *et al.*, 2011).

With the growing popularity of online programs, how to assess the quality of an online course offering is a critical question (Wang *et al.*, 2006). Unfortunately, there is very little literature in relation to the virtual teaching of Lean, with some studies available primarily by Cudney (2011, 2022) and McDermott (2021a, 2021b). This paper discusses the main design and the integration of online Lean education and training and the methods involved in two different organisations.

Thus the summary of the research questions are:

- RQ1: How can Lean education be transferred effectively to the online classroom to emulate the physical classroom without compromising learning, understanding and student experience?
- RQ2: What were the challenges, advantages and disadvantages of virtual Lean online classroom delivery versus a physical classroom or training environment?
- RQ3: Ascertain best practices for Lean online education via benchmarking of two Lean educator organisations

The next section outlines the literature review, followed by a discussion of the methodology involved. Next, the results are presented and discussed, followed by a conclusion.

2.0 Literature Review

Lean has evolved as a continuous improvement methodology with its origins, especially in manufacturing organisations and on the production floor, to one deployed in all types of organisations and services. Lean has been successfully deployed in all areas of organisations and can be deployed in services, healthcare, and financial organisations (McDermott, Antony and Douglas, 2021). To deploy Lean as part of a continuous improvement (CI) program demands that personnel and practitioners have solid basics in Lean (Antony *et al.*, 2021). However, to successfully deploy Lean, an understanding of and education on applying the tools effectively is important (McDermott, 2021; McDermott, Walsh and Halpin, 2021; McDermott *et al.*, 2022). Continuous improvement and Lean programs require practitioners, including engineers and other professionals, to have a solid grounding in Lean basics to aid understanding and effective deployment (Gadre *et al.*, 2011). Imai (1989) referred to Lean techniques and tools as the cornerstones for eliminating waste or "Kaizen building blocks". Many organisations have begun their Lean journey through training, education and implementation in basic Lean tools such as 5S, Kaizen teams, and standardisation, which results in the elimination of waste (Muda), unevenness (muri) and overburdening (Mura) in working processes (Trubetskaya *et al.*, 2022). Progression into more complex techniques and tools evolves as part of Lean thinking once the basics are understood (Gadre *et al.*, 2011).

Many authors have discussed the importance of practical training methods and the use of a classroom environment to train people in Lean or as "obeya" or "Kaizen" areas to aid this learning, application and understanding of Lean (Priolo, 2019). Modern-day education and training require a design of curriculum that provides students with opportunities to utilise and learn the latest technologies (McDermott, 2021). However, despite the pros and cons of virtual online delivery, which have been discussed by many authors (Kock *et al.*, 2007), the COVID-19 pandemic meant that the only option available to deliver modules was online. By providing students with the knowledge and skills to use lean principles and tools to solve real-world problems, these future employees will add immediate value to the companies that hire them (Van Til *et al.*, 2005)

2.1 Designing an online Lean classroom

Prashar (2015) prescribed that online learning tasks should help learners develop higher-level thinking skills, measure their understanding, and encourage and facilitate sharing ideas and problems. This learning can take place in an interactive or collaborative online format. For a successful online classroom, there should be student involvement, a task-oriented environment and the promotion of collaborative learning (Arbaugh, 2014; Salmon, 2013). This requires structured learning of evolution or "scaffolding" of learning tasks in classrooms and classroom activities, albeit virtual (Salmon, 2011, 2013). Unfortunately, literature on teaching Lean virtually or in a flipped classroom is not as prevalent as the published research on online teaching. However, the learnings around online teaching methods can be leveraged and applied to Lean teaching in a virtual environment. However, there are still many related studies of online Lean education and virtual industry-based Kaizen events (Alves *et al.*, 2018; Cudney *et al.*, 2011; Gadre *et al.*, 2011; Suárez-Barraza and Ramis-Pujol, 2010).

Badurdeen et al. (2010) and Cudney et al. (2011) have discussed the importance of simulation and games, problem-based learning (PBL), active learning, blended learning, and flipped learning in teaching Lean as a method of assuring experiential learning (Tortorella, and Cauchick-Miguel, 2018).

Alves et al. (2018) discussed how learning experiences were improved when educational tools were made based on active methodologies, such as hands-on simulation in a Masters's class. Gadre et al.(2011) utilised a simulation designed around a traditional push-type mass production line with the students improving the line by implementing lean techniques. This enabled the students to experience the advantages of lean real-time while facing real-life problems encountered in implementing it. Tortorella and Cauchick-Miguel (2018) found that problem-based learning (PBL) is a complementary method for educating in Lean as it exposes students to actual problems when implementing lean tools.

These aforementioned approaches are all conducive to teaching Lean. Moreover, a PBL approach is more engaging and intellectually challenging than traditional approaches as learning is "active" (Daniel, 2020; Tortorella and Cauchick-Miguel, 2018). A sense of community is also central to student engagement and satisfaction in a virtual classroom, and breakout rooms, discussions, and teamwork help develop a sense of community (Berry, 2019). Finally, lean techniques and tools are considered the cornerstones for eliminating waste. Therefore, Lean training, approach, deployment, and education can begin by implementing basic Lean and Six Sigma techniques and tools (Byrne *et al.*, 2021; Suárez-Barraza and Ramis-Pujol, 2010).

Then, Lean thinking evolves towards more complex techniques and tools that are considered to be part of Lean thinking, such as just-in-time (JIT) Kanban set-up, poka-yoke (error-proofing), single minute exchange of dies (SMED), and Hejunka (levelling production)(Gadre *et al.*, 2011). Given this, the research suggests that learning about Lean within a virtual classroom can aid this learning, application and understanding of Lean.

2.2 Lean online and virtual training delivery

Many factors affect an organisation's transition to online and virtual training delivery. However, COVID-19 has driven all educational or training institutions to online delivery throughout the pandemic. Online education and delivery can include cost savings, shorter training delivery times, flexibility and convenience of training delivery and accessibility, training accessibility content and consistency, enabling and facilitating knowledge management, and no need for travel. However, the disadvantages include lack of human contact, ability to read and respond to body language, resistance to change, confusion about technology, broadband reliability and lack of organisational resources (Yin, 2016). In addition, companies can be confused by many vendors, content providers, and tools available in the market that promise to deliver a complete e-learning solution (Fry, 2001). However, Cudney et al. (2011) highlighted the importance of the virtual learning environment (VLE) in enhancing undergraduate engineering education by utilising lean technology as a learning tool. Using the VLE helped foster student development via active learning in the classroom and through projects based on real-world challenges, thus improving student learning, motivation, and retention.

2.3 Virtual Meetings in other sectors

As mentioned, COVID-19 drove increased virtual meeting deployment and development in all sectors. Virtual meetings can deliver enhanced access to integrated, high-quality and efficient virtual meetings and help advance new norms and effective alternatives for innovative research, education and information dissemination in many sectors and areas (Rubinger *et al.*, 2020; Sox *et al.*, 2014). For example, within the Marketing sectors, focus groups are important in identifying customer and consumer opinions and preferences, but many marketers have adopted the Delphi technique for online focus groups (Sox *et al.*, 2014). Rubinger et al. (2020) highlighted how orthopaedic research could be shared and disseminated and succeed via virtual platforms and meetings.

Many best practices have been identified regarding good virtual meeting practices and design in all sectors and organisations, leading to increased opportunities for sharing virtual learning delivery (Rubinger et al., 2020). Technology is quickly evolving, and virtual meetings need to embrace enhanced meeting delivery and educational opportunities by keeping abreast of technology for the promotion, planning and execution of their meetings(Sox *et al.*, 2014). Frisch and Greene (2020) put forward 12 best practice steps for running virtual meetings. Six of these were more around technology access and utilisation, including using video, having an auto-dial in option, testing the technology ahead of time, making sure faces are visible, sticking to meeting basics, minimising presentation length, and lastly, using an icebreaker. The remaining steps were more related to engaging the audience via assigning a facilitator, calling on people, capturing real-time feedback, capturing tough issues, and reviewing meetings lessons learned to improve for next time. In relation to obeya and its application in virtual meetings (K. Aasland and D. Blankenburg, 2012) stated in their study ton the use of the obeya that modern technology allows active participation in the activities in each of the meeting rooms without being physically present. That means that activity, including active real-time view, is possible for participants at both the same place and/or different places at the same time or allows a passive view;

simply observing is also obvious in all rooms. Within product development with its interdependence of tasks, this socialisation aided by the obeya is critical as creating integrated product-development work streams leads to a more optimised process(Morgan and Liker, 2020).

2.4 Summary of literature themes related to Lean teaching online

A summary of the key themes of the literature in relation to online cores design and training, as well as Lean teaching online, has been summarised in Table 1. While there was much literature on online teaching, there was less on teaching Lean online. As problem-solving is integral to Lean as is teamwork, respect and employee engagement works related to teaching Lean online were leveraged such as studies by Cudney et al. (2011), Cudney et al. (2020), Gadre et al. (2011), McDermott (2021), and McDermott et al. (2021). Several studies by Cudney discussed the importance of teaching via practical examples, scenarios and gamification.

Table 1: Literature themes related to Online Learning

Themes	Source
Course organisation & design Delivery technology/online engagement methods Student classroom collaboration Timely feedback to students and responses to queries Lean games -gamification Simulations Active learning Practical scenarios Student Feedback	(Badurdeen *et al.*, 2010) (Berry, S., 2019) (McDermott, 2021) (McDermott, Walsh, *et al.*, 2021) (Salmon, 2011) (Arbaugh, 2014) (Junus *et al.*, 2021) (Tortorella, G and Cauchick-Miguel, 2018) (Cudney *et al.*, 2011) (Cudney *et al.*, 2020) (Subhash and Cudney, 2018) (Gadre *et al.*, 2011) (Pastore and Falvo, 2010)

3.0 Methodology

3.1 Case Study organisations -background

Two case study organisations were chosen for this research. The case study method is used as it facilitates research by focusing on a specific case, learning more about the subject in question and studying the relationship between theory and application (Yin, 2016).

The approach in this research was to compare and contrast the experience of 2 Irish organisations in transitioning their Lean learning online. By benchmarking one organisation against the other, the author was able to compare the experiences of the learners and teachers and the quantitative results and best practice delivery initiatives. Benchmarking is an essential tool for continuous improvement of quality (Dattakumar and Jagadeesh, 2003) and thus will aid improvement of online teaching delivery by comparing the approaches taken in the 2 case study organisations. The themes and items that the benchmarking was most concerned with were course organisation, delivery technology, student classroom collaboration, timely feedback to students and responses to queries, online engagement methods, Lean games, recordings, and assignment grades.

One organisation, as previously mentioned, was a leading Irish university, and the other was a private-sector Lean training provider in Ireland. The university students whose Lean teaching was transferred online were full-time postgraduate students, many of whom had no experience in manufacturing or other industry types. There were 60 students involved in total. Before COVID-19, the training provider delivered Lean training in public locations and in-company training classrooms. The providers' typical service customers are multinational corporations and employed adult learners interested in professional development and training. By utilising both organisations in this study, the researchers hope to leverage learnings from both approaches and benchmark these approaches for mutual benefit.

3.2 Mixed Methods Approach

A mixed-method approach was taken to ascertain the experiences of the trainees and students who received online lean teaching and training (Creswell, 1999). Mixed-method data via quantitative survey data and qualitative interviews were collected. Qualitative interviews were deemed an excellent method to capture the richness of the student experiences and aid research discussion and analysis of learnings (Yadav, 2022). In this research, a qualitative approach seeks to predict and control social phenomena to generalise the findings of a population and encourage replication of the results (Park and Park, 2016). In addition, qualitative semi-structured interviews were conducted with students, trainers and university tutors within the training provider and the university to assess the challenges, experiences, benefits and results of transitioning to an online Lean virtual delivery module.

Quantitative surveys can also gather information from a larger population to generate more data (Evans and Mathur, 2005). With qualitative research, the results are not definitive and cannot be used to generalise the population of interest but develop an initial understanding of the research area, which aided the development of a quantitative survey to gain further evidence to answer the R.Q.s (Park and Park, 2016). Before distribution, the survey was piloted with a sample of trainers, students and lecturers (Tashakkori *et al.*, 1998). Extensive piloting can help identify any aspects of the survey that are unclear or not value-added (Hazell and Berry, 2022). Any issues or feedback about the survey were taken on board by the author, and the survey was edited.

Following online Lean training, attendees from participating case study organisations were asked to complete the survey questionnaire for each training course. The questionnaires listed questions about the online training delivery measured on a Likert scale (table 2).

Table 2 - List of Questions in the Student Survey

#	Question
1	Considering the general objectives of the course, what was your overall rating? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
2	How well did the course/training deliver the "Learning Outcomes"? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
3	If applicable, have you applied the new skills learned in your workplace? Yes or No
4	Trainers/Tutor's presentation/teaching skills 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
5	Use of technology to aid learning (e.g. Zoom/Blackboard) 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
6	Trainers/Tutor's ability to answer questions 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
7	Encouragement to participate 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
8	Pace of course delivery 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
9	How would you rate the clarity of assessment/classroom activity requirements? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor
10	Would you recommend this course to a colleague/another student?Yes or No
11	If you have completed Lean training previously in a physical classroom environment, please state which Lean training environment you prefer. .(please note; this question is specific to Lean education only) Online, Physical classroom, A mix of both, no preference

3.3 *Data analysis*

The interviews were first recorded, and then the transcripts were saved in Atlas. Ti 22 software. Coding was performed to ascertain the students' experiences in both organisations related to the benchmarking criteria and interview answers. Following Cascio *et al.* (2019), open coding was carried out by creating a list of themes within data and axial coding by linking the study and benchmarking theme subcategories to higher-order themes. These themes were categorised and linked (Charmaz and Belgrave, 2007). In order to ensure inter-rater reliability, as 3 researchers conducted coding, the inter-rater reliability was measured and found to be 98% (Creswell and Cresswell, 2003). The inter-rater reliability assesses and increases the validity and reliability of the study results (Tashakkori *et al.*, 1998). The survey results were calculated in terms of % satisfaction, dissatisfaction, or agreement with a 5-point Likert scale.

4.0 Results

4.1 Development of online Lean learning modules

This section of the paper describes the design of online Lean teaching activities. Both case study organisations utilised the online classroom as the online Kaizen room where each student worked on a problem. Students had to bring a "problem" or "project" from their workplace to the training organisation's training. They subsequently applied Lean thinking and tools to that “problem”. This learning was applied via a series of Lean exercises that could be carried out in the virtual classroom, which became the online “kaizen” room or “obeya”(Table 1). The Kaizen room, or obeya room, was the key tool for facilitating teamwork and completing projects to deploy the Lean training and learning (Priolo, 2019). The students were given basic education in Lean and different tools in an iterative manner and then encouraged to utilise the tools and apply them to their projects. In order to ensure benefits for the training providers' customers, no student came to training without a problem from the organisation to work on.

The students in the university had not worked in a manufacturing environment, nor had they had access to one and were not familiar with Lean or operations. Hence the “problem” or a case study project scenario was given to them. For postgraduate students, online delivery is more amenable to these learners as they have greater self-regulation, acquire learning strategies, and can adjust to online environments relatively quickly (Arbaugh, 2014; Arbaugh and Hwang, 2006).

As with the training organisation, the university assignments or "kaizen", as it was framed, were based on applying Lean concepts to a problem in an online environment. The university lecturers designed a “kaizen” based on a theoretical company called "ABC", which produces and deliver sandwiches and could equally be considered a manufacturing or service-type environment. Foodstuffs were picked as a product instead of a product made of complicated components. The Kaizen case study was designed to present an ineffective wasteful organisation with many opportunities for improvement.

The case study game gave the university students information about the company's performance and key performance indicators (KPIs). In addition, an overview of how orders are received, processed, and downloaded and other elements of the supply chain process were given in a descriptive scenario: production, shipping, and delivery. The students carry out various activities; waste analysis, developing KPI scorecard, VSM, takt time analysis, root causing including brainstorming, and cause and effect analysis. The lecturer then explained Lean principles, and students were encouraged to apply 5S, Hejunka, poke yoke and implement pull and flow.

4.2 Design of the Virtual Classroom

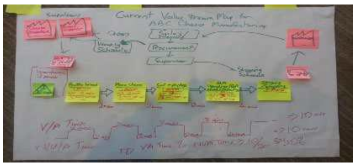
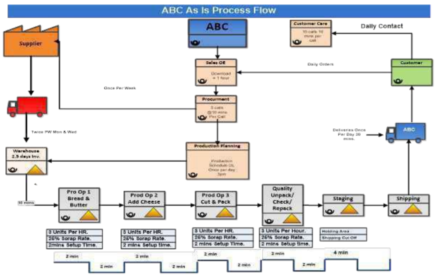
The virtual learning environment (VLE) platform is utilised as Blackboard, the university VLE of choice. The training organisation utilised Zoom with a Moodle VLE. Both organisations divided students into breakout rooms to brainstorm scenarios and apply Lean tools and concepts. The breakroom exercises followed a problem-solving approach so that each breakout room exercise built on to the previous activity and task. Within the breakout rooms, the lecturer or trainer could recreate the teamwork and brainstorming aspects of Lean in the workplace and physical classroom. The lecturer or trainer moved between breakout rooms to chat with and advise the students to evaluate and ensure learning. After each activity, the lecturer or trainer would bring the teams back into the virtual classroom, and each group would present their progress. The progress presentation was essential to ensure that the exercise was understood, provide feedback to the students, and share ideas within the class. The lecturer presented some theory and background to each Lean tool or practice and various Lean principles before commencing with the next breakout room exercise.

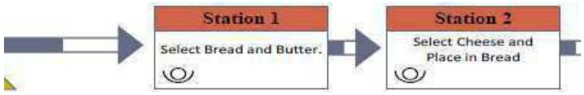
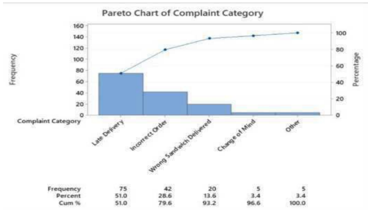
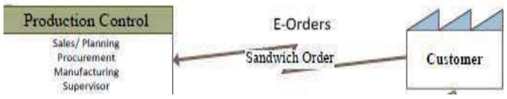
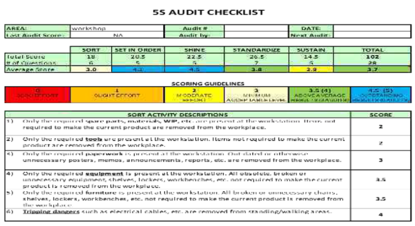
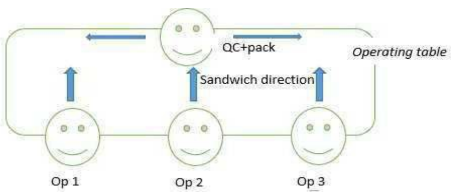
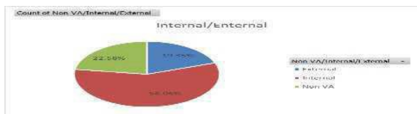
The summary of the learning design and activity in the Lean online classroom is demonstrated in Table 3. Table 3 demonstrates the individual exercises and assessments in the virtual classroom. Column 1 highlights the assignment or exercises given to the students to complete. In this research, postgraduate students and trainees applied Lean Six Sigma tools such as Value Stream Mapping (VSM), 5S, Visual Management, Single Minute Exchange of Dies (SMED), Kanban, Plan-Do-Check-Act (PDCA), DMAIC, process and effect, 5Whys, process mapping, poke yoke, JIT and Kanban amongst others. In addition, they developed their project or case study (for university students) as part of a Lean virtual kaizen.

Column 2 demonstrates how that learning is completed or evidenced by the students. This occurred via students integrated into teams, utilising problem-based learning, active learning and an obeya system situation as if they had been in a flipped physical university or workplace classroom. While column 3 highlights how the exercise and learning were reviewed, shared and feedback provided in the Lean classroom. Evidence of a sample student output is presented, and the reiteration that "Lecturer and peer review is provided in the online classroom". In both organisations, the students submitted with their groups (alternating in presenting). This helped provide instruction from the trainer or lecturer, validated that the learning had taken place and was understood and enabled reflection. Instructors could give positive and constructive feedback (Salmon, 2011).

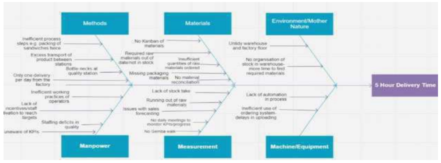
Table 3**:** How Lean Principles and Concept Learning were applied within the virtual kaizen classroom (both university and training organisation examples) (McDermott, Walsh, *et al.*, 2021)

Lean Tools Utilised and taught in Online Kaizen Classrooms.	**Learning demonstrated and deployed in Virtual Classroom/ BREAKOUT ROOMS**	**Review, Sharing & Feedback in Virtual Classrooms**
SMART problem statement The students were given enough information to develop a problem statement and set goals and objectives for the kaizen activity.	Students collaborate in the online classroom to develop a problem statement and set goals and objectives for the kaizen activity.	From a manufacturing point of view, ABC Sandwich Company's operations team has the capacity to produce 3 units/hour, with a TAKT time of 4 units per hour meaning that they are not meeting customer demand. This LSS project will aim to meet customer demand by reducing process cycle time in manufacturing by 50% from 20 minutes to 10 minutes per sandwich within three months/ by the end of quarter 3. Lecturer & Peer Review in the online classroom
Key Performance Indicator (KPI) Scorecard Students were given a suite of data and performance measures related to Productivity, Delivery, Quality and Cost.	Students collaborated and developed a KPI scorecard based on the information given.	Key Performance Indicator Process Cycle Time Yield Delivery Time Customer Complaints Lecturer & Peer Review in the online classroom
Process Mapping Students were asked to draw a process map based on the steps outlined in the case study.	Students collaborated and designed a "Current" Process Flow.	 Lecturer & Peer Review in the online classroom
Non-Value Add wastes Several Lean wastes are presented within the case study for the student to identify (more than thirty examples of the 8 Lean Wastes were contained therein.	Students brainstormed and presented the eight waste types observed in the case study.	Waste: Transportation — Example: • Time and effort spent transporting product between three stations in the manufacture of one unit but do not add value to the customer • Over handling of materials leading to damage of product Waste: Inventory — Example: • Raw materials that are not used by their expiry date Lecturer & Peer Reviewing the online classroom.

Value Stream Mapping and Takt time Based on the case study information, the students were asked to identify non-value wastes and potential areas which could be causing problems. Finally, takt time was established based on the VSM and data provided.	The students worked on creating a VSM within the classroom breakout rooms utilising a virtual whiteboard. Students presented a virtual VSM and takt time calculations.	  Lecturer & Peer Review in the online classroom

Pull and flow principles. Students were asked to look at the process and ascertain where pull and flow were lacking and where they could be improved.	Students brainstormed ideas on pull and flow improvement and presented them in the online classroom.	 Lecturer & Peer Review in the online classroom
Check sheets, Histograms, Pareto, and **Control Charts.** Data was provided to enable students to utilise and learn about essential quality management tools.	Students presented examples of tool applications and learnings.	
JIT & Kanban Just as Time and Kanban explained, opportunities were presented within the case study to explain the theory.	Students brainstormed where Kanban and JIT may be utilised in the case study.	 Lecturer & Peer Review in the online classroom
Poke Yoke an example of process errors in the case study was presented, and students were asked to error-proof the process	Students gave examples of error-proofing about the issues presented.	One-Owner Elimination of manual order entry – real-time E-orders  Lecturer & Peer Review in the online classroom
5S Students were given examples of untidiness with the organisation in the warehouse, production floor and offices; they were then asked to state how they would carry out a 5S based on the information they had. Finally, they were asked to develop a 5S audit template.	Students presented a 5S program and 5S audit.	 Lecturer & Peer Review in the online classroom
Hejunka Students were given examples of inadequate flow and unevenness within the order scheduling process and the outgoing shipping process and asked to brainstorm how they would improve it by using Hejunka to implement evenness.	Students presented where Hejunka was required and how it could be utilised.	 Lecturer & Peer Review in the online classroom
SMED Students gave examples of slow turnarounds and brainstormed in line with 5S examples.	Students presented SMED opportunities in the customer order processes and within the production line.	

<table>
<tr><td>where SMED could be applied.</td><td></td><td>Lecturer & Peer Review in the online classroom</td></tr>
<tr><td>Cause & Effect diagrams

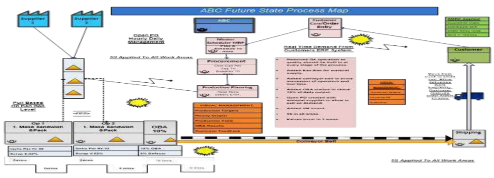
To root cause issues identified throughout the Kaizen, students were encouraged to apply the C&E diagram to two problems; 1) Reasons for deliveries taking up to 5 hours and 2) reasons for high defect rates and complaints.</td><td>Students presented C&E diagrams and how they applied cause screening to the issues identified in the cause and effect and prioritised the issues based on a high, medium, and low potential for causing problems and fixing them.</td><td>

Lecturer & Peer Review in the online classroom</td></tr>
<tr><td>5 Whys

Students were asked to further utilise the 5 Whys tools to develop a root cause and identify corrective actions for issues within the C&E process.</td><td>5 Whys scenarios presented for various root causes</td><td>1. Why are the box labels being put on incorrectly?
Operators placing incorrect label on product boxes i.e. mixing up label for secondary and tertiary packaging
2. Why are operators mislabeling boxes?
They are mixing up the labels that are required for each stage of the packaging process
3. Why are they mixing up labels?
Labels are not always legible and can be difficult to read.
4. Why?
Issues with printing equipment and staff skills using the equipment
5. Why?
Staff have not received adequate training and machines are not being maintained adequately

Solution: Staff training and starting a routing maintenance schedule for equipment including label printer

Lecturer & Peer Review in the online classroom</td></tr>
<tr><td>Future State Value Stream Map

Students were asked to brainstorm and design a future VSM with improvements in flow, pull and waste reduction and new Takt times.</td><td>Future VSM with improvements presented</td><td>

Lecturer & Peer Review in the online classroom</td></tr>
<tr><td>New KPI Scorecard

Students estimated how changes and actions implemented had affected the original KPI metrics.</td><td>New KPI scorecard presented with justification for reducing costs, quality defects, improved delivery, etc.</td><td>Table 7. Estimated score card for target KPIs 6 months after completion of LSS project<table><tr><th>Process/KPI</th><th>Improvements Made</th><th>Before</th><th>Results</th></tr><tr><td>Process Cycle Time</td><td>- Changes to line layout
- Reduction of production Stations from 3 to 2
- One-piece flow</td><td>20 minutes per unit and 2 minutes set up time/unit</td><td>10 minutes/unit and 1 minute line clearance between units</td></tr></table>Lecturer & Peer Review in the online classroom</td></tr>
<tr><td>Reflection & Kaizen Closeout

Students were asked to reflect on Lean methods and how tools helped.</td><td>Reflection discussion and Kaizen close out held. Congratulations to Team.</td><td><table><tr><th colspan="2">Improvements from Lean Principles Adopted:</th></tr><tr><th>Before</th><th>After</th></tr><tr><td>• Warehouse housed 2.5 days of inventory and staff were not aware when resources where running low.
• Parts getting mixed up and individuals having difficulty finding parts.
• Throughout ABC areas are generally untidy, non-essential equipment is getting in the way of production and some individuals and items are difficult to locate because of a lack of signage and</td><td>• <u>Kanban</u> system helps eliminate the need for a warehouse as items remain stocked on the floor by the supplier This system means that the produce being used for the product is consistently fresh.
• <u>Using 5S principles</u> organise storage and wall organisers to help operating staff to keep their parts and equipment organised.
• <u>5 S's</u> practice disposes of all non-essential items and equipment. Signage and labelling is used throughout to indicate locations of staff members or items</td></tr></table>Lecturer & Peer Review in the online classroom</td></tr>
</table>

4.3 Survey Results

In this research, postgraduate university students and a training provider organisation's students applied many Lean tools such as Value Stream Mapping (VSM), 5S, Visual Management, Single Minute Exchange of Dies (SMED), Kanban, Plan-Do-Check-Act (PDCA), DMAIC, process and effect, 5 Whys, process mapping, poke yoke, JIT and Kanban amongst others (Table 2). In addition, they developed their project (in the case of the trainee organisation) or case study (for university students) as part of a Lean virtual kaizen.

This occurred via students integrated into teams, utilising problem-based learning, active learning and an obeya system situation as if they had been in a flipped physical university or workplace classroom. In both organisations, the students submitted with their groups (alternating in presenting). This helped provide instruction from the trainer or lecturer, validated that the learning had taken place and was understood and enabled reflection. Instructors could give positive and constructive feedback (Arbaugh and Hwang, 2006; Salmon, 2011).

One hundred sixty-four students were surveyed. 63% were from the training organisation, and 37% were from the university. The same questions were asked to each group and compared. One question did not apply to the student population about whether Lean learning was applied in the workplace. Although 2 diverse populations answered the survey questions, the satisfaction ratings of the online Lean training were extremely high in both organisations. A particularly interesting result was in terms of the use and application of the tools after the training by the training organisations' students. 98% of students stated they had applied the new Lean skills and tools in the workplace (table 4).

Table 4 - Student Survey responses

#	Question	
1	Considering the general objectives of the course, what was your overallrating? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 93% gave a rating of "Excellent." University: 98% gave a rating of excellent
2	How well did the course/training deliver the "Learning Outcomes"? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 99.5% gave a rating of Excellent. University: 100% replied Excellent
3	If applicable, have you applied the new skills learned in your workplace? Yes or No	Training organisation: 98% Replied 'Yes.' University: n/a
4	Trainers/Tutor's presentation/teaching skills 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 94% gave a rating of Excellent. 6% replied Very good University: 98% gave a rating of Excellent
5	Use of technology to aid learning (e.g. Zoom/Blackboard) 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation:88% gave a rating of Excellent, with 12% being Very good/good University: 99% gave a rating of Excellent
6	Trainers/Tutor's ability to answer questions 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 94% gave a rating of Excellent

		University: 98% gave a rating of excellent
7	Encouragement to participate 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 91% gave a rating of excellent University: 94% gave a rating of excellent
8	Pace of course delivery 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 98% University: 99.5% gave a rating of excellent
9	How would you rate the clarity of assessment/classroom activity requirements? 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Adequate, 1 = Poor	Training organisation: 87% gave a rating of excellent University: 96% gave a rating of excellent
10	Would you recommend this course to a colleague/another student? Yes or No	Training organisation: 96% stated Yes University: 100% stated Yes
11	If you have completed Lean training previously in a physical classroom environment, please state which Lean training environment you prefer? (please note; this question is specific to Lean education only) Online, Physical classroom, A mix of both, no preference	Training organisation: Online: 40% preferred Physical classroom: 30% preferred A mix of both: 20% preferred No preference: 10% preferred University: n/a

Further to the above results, a chi-square analysis was performed using SPSS to determine if there was a statistically significant difference in student grades %s between one sample cohort of online and face-to-face students before and after COVID-19 delivery. There was a high % of A's in students enrolled in the face-to-face classes prior to COVID-19 (mean=71.5%), but the online class (during COVID-19) also maintained a high percentage of A's (mean = 72.1%) which was very negligible. Therefore, the difference in student performance was deemed not statistically significant, $\chi2$ (1, N = 250) = 0.404, $p < 0.05$).

4.4 Interview Results

Semi-structured interviews were carried out with the stakeholders from this case study research: the trainers, lecturers, and students. A sample of participants from multinational organisations who sponsored the training was also included. A sample size of 20 was deemed appropriate as it represented the mix of stakeholders involved in this case study(Creswell and Poth, 2016). A mix of 10 trainers and lecturers and some clients of training organisation made up the interviewees, with the rest being students. Interview questions aimed to ascertain the stakeholders' experiences moving to an online Lean learning model. The trainers from the training organisation discussed the benefits of not having to travel for training sessions. University lecturers stated the same. However, the trainer's comments were limited to "*the work involved in ensuring that the practical class activities could be replicated online*" and the "*Lean activities and design of those activities took time*". The training organisations' clients, mostly multinationals, discussed the benefits of "*not having to send 12-13 people offsite for a day or more at a time*". Having spaced out smaller online virtual training slots meant better utilisation and flexibility with employee time.

The challenges met by the lecturers and training in both organisations were that "*we had to work harder and faster to stimulate students"*. Both lecturers and trainers tutors noted that "*they had to verify learner engagement in the virtual environment continuously*". While Zoom and Blackboard were proven to be very effective platforms, the tutors had to be "*more active*" and "*we were conscious to constantly elicit learners to contribute comments or feedback*" instead of waiting for them to come voluntarily. Challenges in "*ensuring participation and active listening*" were overcome by requesting that cameras remain turned on. The lecturers, in particular, noted that students were used to a passive model of taking in lecture information, and they "n*eeded to check in and engage students*".

Both organisations touted breakout rooms and class polls as "*essential to assist with learner interaction and engagement*". While "sharing the screen and document function has been extremely effective" for integrating and sharing Lean exercises from breakout rooms and providing feedback.

4.5 Benchmarking Summary

The high-level comparison of the benchmarking exercise between the two case study organisations is summarised in Table 5. The deployment and execution of the online classroom design and delivery in relation to Lean teaching were very similar despite being carried out independently. Both organisations utilised experienced Lean tutors and former Lean industry professionals, so the design was very interactive to emulate the "active learning" of a face-to-face classroom and organisational-based environment.

Table 5: Summary of Benchmarking criteria and themes in two case study organisations

Benchmarking Criteria	Results
Course organisation	Lecturer/Training Instructor carries out scheduling as appropriate via the online calendar.
Delivery technology/online engagement methods	University: Blackboard VLE plus Zoom Training Provider: Moodle VLE plus Zoom/MS Teams
Student classroom collaboration	Both organisations: All assignments in a virtual classroom are designed to be collaborative

Timely feedback to students and responses to queries	University & Training Organisation: Both provided real-time classroom feedback on games and exercises during the online session.
Lean games	Both organisations took a “game” and “active learning” approach with Lean exercises and activities.
Recordings	University & training organisation: Recordings were available after lectures, but live attendance was mandatory in both case study organisations to enable participation in training assessments in a live class and assignment room.
Assignment grades	Varied between 2-4 weeks of activity completion depending on lecturer timetable and trainer schedule.
Student Feedback	University: Online student feedback survey placed on VLE Trainer organisation: Completed as part of an online class and emailed to the trainer.

5.0 Discussion

This study has demonstrated the importance of teaching online in a Kaizen format that emulates the active and blended classroom learning environment and an organisational environment of brainstorming, huddles, teamwork and practical completion of process maps, value stream maps, and root causing via collaboration. Many studies, especially since COVID-19, have highlighted how Lean and other subject area teaching can be transitioned effectively to the online classroom by effective learning design (McDermott, Walsh *et al.*, 2021; Mohandas *et al.*, 2022; Tortorella and Cauchick-Miguel, 2018) and this research corroborated those findings. In addition, RQ1 investigated how a) Lean education is transferred effectively to the online classroom to emulate the physical classroom b)without compromising learning, understanding and student experience. This learning transfer was demonstrated in both organisations under study via the completion and presentation of evidence of Lean learning in the online classroom and via feedback from students (RQ1). Lean Engineering education calls for both content and competency proficiency, and this assignment was designed to provide opportunities to demonstrate these competencies. This combination is necessary for professional engineering career success (Flumerfelt et al., 2015).

Learning understanding, experience and effectiveness was also measured by student evaluation (surveys and interviews) as they are a recognised best practice for understanding online teaching effectiveness (Bangert 2006). The interview and survey results demonstrate a very high satisfaction rate with Lean learning, registering an opinion of the students that there was "no compromise" in Lean learning and understanding via the virtual delivery model. The online delivery format's perspective does not affect student learning outcomes and has been dubbed the "no-significant-difference" perspective (Summers *et al.*, 2005).

Estébanez (2017) found in a comparison of various teaching methods of cooperative and traditional learning in engineering education that none significantly affected student academic achievement, which reflected the findings in this study also across both organisations.

Following Gillespie (1998), online learning tasks were designed to help Lean learners develop higher-level thinking skills and evaluate their understanding, mediated by sharing ideas and problems with the content using interactive or collaborative online formats. The problem-based online Lean classroom set-up and design was based on the following criteria of student involvement, task orientation, innovation and promoting collaborative learning, and based on the mixed methods study result, was highly effective (Prashar, 2015). Online Lean teaching includes varied assignments and well-designed assessments to challenge students and target their focus (Daniel, 2020).

RQ2 investigated the a)challenges, b)advantages and c)disadvantages of virtual Lean online classroom delivery versus a physical classroom or training environment. As highlighted previously, having accessible technology that students can utilise and engage with, as well as a classroom environment that promotes collaborative learning, were the challenges faced by online teachers. The students and tutors both highlighted many advantages of online learning. These advantages include lack of travel, convenience, and ease of access, and the online classroom was practical and active with active peer interaction and tutor feedback. The disadvantages included a lack of physical face-to-face tutor interaction, which some students preferred, getting used to the technology, and the tutors feeling they had to work harder on engagement and maintaining students' attention. These findings aligned very much with previous studies related to online teaching. For example, Mohandas *et al.* (2022) identified major themes that impact online teaching effectiveness, such as good course organisation, peer collaboration and class engagement, activity games, valuable course content, and timely student feedback and response. Badurdeen *et al.*(2010) and Berry (2019) discussed how simulation and games were important in aiding online teaching success and a challenge to ensure active learning, participation and engagement by replicating the problem-solving element of the physical classroom. McDermott (2021) and McDermott, Walsh, *et al.* (2021), in 2 studies carried out on Lean teaching online during COVID -19 a study demonstrated similar advantages and disadvantages as well as challenges to transferring Lean teaching online. The importance of well-designed practical games and simulations in the online classroom was a theme throughout both studies.

RQ3 was to ascertain best practices for Lean online education via benchmarking of two Lean educator organisations. From a benchmarking of the approaches taken by the two organisations in this study, it was found that both organisations (independently of each other) adopted remarkably similar design, education and delivery approaches to online Lean education. Furthermore, interviews in both organisations with the personnel discussed the importance of lean online activities, all by very experienced practitioners in lean with vast industry experience; thus, similar approaches were found in teaching approaches. This "game" design of active Lean learning and the use of deployment of tools was deemed instrumental in effective Lean learning in many other studies on online and blended Lean education (McDermott, Walsh, *et al.*, 2021; Tortorella and Cauchick-Miguel, 2018). The only difference in the kaizens conducted online in both organisations was that the case study in the university was a hypothetical scenario populated with fabricated university data rather than a real organisational problem. Also, within the training organisations, the students implemented real-time corrective actions in their organisations as part of the virtual Lean kaizens.

In summary, while there has been some literature published in relation to teaching Lean online and virtually, this study fills a gap by presenting a practical case study of Lean deployment in an online classroom. This study also leveraged 2 previous studies by one of the authors, thus taking note of best practices and lessons learned in previous online Lean learning designs. Other authors have discussed the importance of the online obeya (K. Aasland and D. Blankenburg, 2012), the use of online gamification (Subhash and Cudney, 2018) and simulation (Badurdeen *et al.*, 2010), and this study takes the approach of incorporating several exercises and tasks to design an online Lean module and achieve its learning objectives.

6.0 Conclusion

This study met the research objectives to describe how Lean education can be transferred effectively to the online classroom and emulate the physical classroom without compromising learning, understanding and the student experience. While there were some challenges in designing and delivering Lean virtually, the results demonstrate that good design enables effective learning. Furthermore, the benchmarking of the two organisations and their approaches to online Lean education demonstrated a remarkably similar design, training and teaching process.

Transferring Lean education online is not straightforward. The highly interactive nature of Lean education and the need for implementing Lean tools in a classroom and student peer-to-peer learning and interaction with the lecturer or facilitator need to be replicated. While a limitation of this study is that it is impossible to definitively state which model, online or physical delivery face-to-face, was better – qualitative and quantitative measures can provide a high level of confidence in virtual Lean learning and provide feedback for future design changes.

This replication can be achieved by good design of Lean scenarios, concepts, games and problems that can be worked on needed to ensure that the quality of learning, the qualitative student learning experience and even the academic quantitative results obtained were not adversely affected. The research demonstrated the development of a user-friendly, virtual learning environment wherein the students studying Lean could apply lean tools in a scenario and game format with hypothetical or real manufacturing problems. This fostered the student's Lean knowledge through active learning and application. Other universities and training organisations and organisations employing Lean programs can leverage this research in optimising and enhancing their online Lean training and delivery, especially in a post-COVID-19 environment of more working from home.

Future research in this area would involve incorporating more simulation software into the online classroom and using virtual reality (V.R.) in the online classroom to enable more active learning, and virtual Gemba walks. Simulation and V.R. can potentially enhance Lean learning and the student experience and are an area for further investigation.

{Citation}

References

Alexander, B., Ashford-Rowe, K., Barajas-Murphy, N., Dobbin, G., Knott, J., McCormack, M., Pomerantz, J., *et al.* (2019), "EDUCAUSE Horizon report 2019", *Higher Education Edition*, pp. 3–41.

Alves, A.C., Flumerfelt, S., Moreira, F. and Leão, C.P. (2018), "Effective Tools to Learn Lean Thinking and Gather Together Academic and Practice Communities", presented at the ASME 2017 International Mechanical Engineering Congress and Exposition, American Society of Mechanical Engineers Digital Collection, doi: 10.1115/IMECE2017-71339.

Antony, J., Lancastle, J., McDermott, O., Bhat, S., Parida, R. and Cudney, E. (2021), "An Evaluation of Lean and Six Sigma Methodologies in the U.K. National Health Services", *International Journal of Quality & Reliability Management*.

Arbaugh, J.B. (2014), “What Might Online Delivery Teach Us About Blended Management Education? Prior Perspectives and Future Directions”, *Journal of Management Education*, SAGE Publications Inc, Vol. 38 No. 6, pp. 784–817, doi: 10.1177/1052562914534244.

Arbaugh, R.B and Hwang, A. (2006), “Does ‘teaching presence’ exist in online MBA courses? - Learning & Technology Library (LearnTechLib)”, *Internet & Higher Education*, Vol. 9 No. 1.

Badurdeen, F., Marksberry, P., Hall, A. and Gregory, B. (2010), “Teaching Lean Manufacturing With Simulations and Games: A Survey and Future Directions”, *Simulation & Gaming*, SAGE Publications Inc, Vol. 41 No. 4, pp. 465–486, doi: 10.1177/1046878109334331.

Berry, S. (2019), “ERIC - EJ1210946 - Teaching to Connect: Community-Building Strategies for the Virtual Classroom, Online Learning, 2019-Mar”, *Online Learning*, Vol. 23 No. 1, pp. 164–183.

Byrne, B., McDermott, O. and Noonan, J. (2021), “Applying Lean Six Sigma Methodology to a Pharmaceutical Manufacturing Facility: A Case Study”, *Processes*, Vol. 9 No. 3, doi: 10.3390/pr9030550.

Carswell, S. (2020), "Medtech sector seeks special status to keep Covid supplies flowing", *The Irish Times*, 21 March.

Cascio, M.A., Lee, E., Vaudrin, N. and Freedman, D.A. (2019), “A Team-based Approach to Open Coding: Considerations for Creating Intercoder Consensus”, *Field Methods*, SAGE Publications Inc, Vol. 31 No. 2, pp. 116–130, doi: 10.1177/1525822X19838237.

Charmaz, K. and Belgrave, L.L. (2007), “Grounded theory”, *The Blackwell Encyclopedia of Sociology*, Wiley Online Library.

Creswell, J.W. (1999), “Mixed-method research: Introduction and application”, *Handbook of Educational Policy*, Elsevier, pp. 455–472.

Creswell, J.W. and Cresswell, J. (2003), *Research Design*, SAGE Publications, Thousand Oaks, CA.

Creswell, J.W. and Poth, C.N. (2016), *Qualitative Inquiry and Research Design: Choosing among Five Approaches*, Sage publications.

Cudney, E.A., Corns, S., Farris, J.A., Gent, S., Grasman, S.E. and Guardiola, I.G. (2011), "Enhancing undergraduate engineering education of lean methods using simulation learning modules within a virtual environment", American Society for Engineering Education (ASEE).

Cudney, E.A., Venuthurumilli, S.S.J., Materla, T. and Antony, J. (2020), "Systematic review of Lean and Six Sigma approaches in higher education", *Total Quality Management & Business Excellence*, Taylor & Francis, Vol. 31 No. 3–4, pp. 231–244.

Daft, R.L. and Lengel, R.H. (1986), "Organisational Information Requirements, Media Richness and Structural Design", *Management Science*, INFORMS, doi: 10.1287/mnsc.32.5.554.

Daniel, S.J. (2020), "Education and the COVID-19 pandemic", *PROSPECTS*, Vol. 49 No. 1, pp. 91–96, doi: 10.1007/s11125-020-09464-3.

Dattakumar, R. and Jagadeesh, R. (2003), "A review of literature on benchmarking", *Benchmarking: An International Journal*, MCB UP Ltd, Vol. 10 No. 3, pp. 176–209, doi: 10.1108/14635770310477744.

Eseryel, D. (2002), "A Framework for Evaluation & Selection of E-Learning Solutions", presented at the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education, Association for the Advancement of Computing in Education (AACE), pp. 275–282.

Estébanez, R.P. (2017), "An approach to cooperative learning in higher education: a comparative study of teaching methods in engineering", *EURASIA Journal of Mathematics Science and Technology Education*, Vol. 13 No. 5, pp. 1331–1340.

Evans, J.R. and Mathur, A. (2005), "The value of online surveys", *Internet Research*, Emerald Group Publishing Limited, Vol. 15 No. 2, pp. 195–219, doi: 10.1108/10662240510590360.

Flumerfelt, S, Kahlen, F.J ., Alves, A. and Siriban-Manalang, A. (2015), "The future state of content & competency-based engineering education: Lean Engineering Education", *Lean Engineering Education*, ASME Press.

Frisch, B. and Greene, C. (2020), “What it takes to run a great virtual meeting”, *Harvard Business Review*, Vol. Frisch, B. and Greene, C., 2020, March. What it takes to run a great virtual meeting. In Harvard Business Review. https://hbr. org/2020/03/what-it-takes-to-run-a-great-virtual-meeting. No. March.

Fry, K. (2001), “E-Learning Markets and Providers: Some Issues and Prospects - Learning & Technology Library (LearnTechLib)”, *Learntechlib.Org*, Vol. 43 No. 1, p. 233.

Gadre, A., Cudney, E. and Corns, S. (2011), “Model Development of a Virtual Learning Environment to Enhance Lean Education”, *Procedia Computer Science*, Vol. 6, pp. 100–105, doi: 10.1016/j.procs.2011.08.020.

Gillespie, F. (1998), “Instructional Design for the New Technologies”, *New Directions for Teaching and Learning*.

Hazell, C. and Berry, C. (2022), “Dilemmas and Decisions in Quantitative-Driven Online Survey Research into Researchers’ Mental Health and Support”, in Bager-Charleson, S. and McBeath, A. (Eds.), *Supporting Research in Counselling and Psychotherapy : Qualitative, Quantitative, and Mixed Methods Research*, Springer International Publishing, Cham, pp. 125–146, doi: 10.1007/978-3-031-13942-0_7.

Homitz, D.J. and Berge, Z.L. (2008), “Using e-mentoring to sustain distance training and education”, *The Learning Organization*, Emerald Group Publishing Limited, Vol. 15 No. 4, pp. 326–335, doi: 10.1108/09696470810879574.

Imai, M. (1989), *Kaizen - the Key to Japanese Competitive Success*, Random House Business Division., New York.

Junus, K., Santoso, H.B., Putra, P.O.H., Gandhi, A. and Siswantining, T. (2021), “Lecturer Readiness for Online Classes during the Pandemic: A Survey Research”, *Education Sciences*, Multidisciplinary Digital Publishing Institute, Vol. 11 No. 3, p. 139, doi: 10.3390/educsci11030139.

K. Aasland and D. Blankenburg. (2012), “An analysis of the uses and properties of the Obeya”, *2012 18th International ICE Conference on Engineering, Technology and Innovation*, presented at the 2012 18th International ICE Conference on Engineering, Technology and Innovation, pp. 1–10, doi: 10.1109/ICE.2012.6297660.

Kock, N., Verville, J. and Garza, V. (2007), "Media Naturalness and Online Learning: Findings Supporting Both the Significant- and No-Significant-Difference Perspectives", *Decision Sciences Journal of Innovative Education*, Vol. 5 No. 2, pp. 333–355, doi: 10.1111/j.1540-4609.2007.00144.x.

McDermott, O. (2021), "The digitalisation and virtual delivery of Lean Six Sigma teaching in an Irish university during COVID-19", *Learning in the Digital Era*, Springer.

McDermott, O. (2021), "The Digitalisation and Virtual Delivery of Lean Six Sigma Teaching in an Irish University During COVID-19.", *Learning in the Digital Era.*, 1st ed., Vol. 610, Springer, Cham, pp. 132–143.

McDermott, O., Antony, J. and Douglas, J. (2021), "Exploring the use of operational excellence methodologies in the era of COVID-19: perspectives from leading academics and practitioners", *TQM Journal.*, Emerald Pub Group, Bingley, U.K. : Vol. ahead-of-print No. ahead-of-print.

McDermott, O., Antony, J., Sony, M. and Healy, T. (2022), "Critical Failure Factors for Continuous Improvement Methodologies in the Irish MedTech Industry", *The TQM Journal*.

McDermott, O., Walsh, P. and Halpin, L. (2021), "A Lean Six Sigma Training Providers Transition to a 100% Online Delivery Model.", *Learning in the Digital Era.*, Vol. 610, Springer, Cham., pp. 144–154.

Mohandas, L., Sorgenfrei, N., Drankoff, L., Sanchez, I., Furterer, S., Cudney, E., Laux, C., *et al.* (2022), "Identifying factors that impact online teaching effectiveness during COVID-19", *Quality Assurance in Education*, Emerald Publishing Limited, Vol. ahead-of-print No. Ahead-of-print, doi: 10.1108/QAE-02-2022-0031.

Morgan, J.M. and Liker, J.K. (2020), *The Toyota Product Development System: Integrating People, Process, and Technology*, Productivity Press.

Park, J. and Park, M. (2016), "Qualitative versus quantitative research methods: discovery or justification?", *Journal of Marketing Thought*, Vol. 3 No. 1, pp. 1–18.

Prashar, A. (2015), "Assessing the Flipped Classroom in Operations Management: A Pilot Study", *Journal of Education for Business*, Routledge, Vol. 90 No. 3, pp. 126–138, doi: 10.1080/08832323.2015.1007904.

Priolo, R. (2019), "What is an Obeya?" *Planet Lean*, 26 September, available at: https://planet-lean.com/what-is-obeya/ (accessed 7 July 2021).

R. Van Til, S. Sengupta, G. Fliedner, M. Tracey, and K. Yamada. (2005), "Teaching lean manufacturing principles using an interdisciplinary project featuring industrial/academic cooperation", *Proceedings Frontiers in Education 35th Annual Conference*, presented at the Proceedings Frontiers in Education 35th Annual Conference, pp. S2J-28, doi: 10.1109/FIE.2005.1612258.

Rubinger, L., Gazendam, A., Ekhtiari, S., Nucci, N., Payne, A., Johal, H., Khanduja, V., *et al.* (2020), "Maximising virtual meetings and conferences: a review of best practices", *International Orthopaedics*, Vol. 44 No. 8, pp. 1461–1466, doi: 10.1007/s00264-020-04615-9.

Salmon, G. (2011), *E-Moderating: The Key to Teaching and Learning Online*, 3rd ed., Routledge, London.

Salmon, G. (2013), *E-Tivities: The Key to Active Online Learning*, 2nd ed., Routledge, UK.

Sox, C.B., Crews, T.B. and Kline, S.F. (2014), "Virtual and Hybrid Meetings for Generation X: Using the Delphi Method to Determine Best Practices, Opportunities, and Barriers", *Journal of Convention & Event Tourism*, Routledge, Vol. 15 No. 2, pp. 150–169, doi: 10.1080/15470148.2014.896231.

Suárez-Barraza, M.F. and Ramis-Pujol, J. (2010), "Implementation of Lean-Kaizen in the human resource service process: A case study in a Mexican public service organisation", edited by Leseure, M. and Hudson-Smith, M.*Journal of Manufacturing Technology Management*, Emerald Group Publishing Limited, Vol. 21 No. 3, pp. 388–410, doi: 10.1108/17410381011024359.

Subhash, S. and Cudney, E.A. (2018), "Gamified learning in higher education: A systematic review of the literature", *Computers in Human Behavior*, Elsevier, Vol. 87, pp. 192–206.

Summers, J.J., Waigandt, A. and Whittaker, T.A. (2005), "A Comparison of Student Achievement and Satisfaction in an Online Versus a Traditional Face-to-Face Statistics Class", *Innovative Higher Education*, Vol. 29 No. 3, pp. 233–250, doi: 10.1007/s10755-005-1938-x.

Tashakkori, A., Teddlie, C. and Teddlie, C.B. (1998), *Mixed Methodology: Combining Qualitative and Quantitative Approaches*, Vol. 46, sage.

Tortorella, G and Cauchick-Miguel, P.A. (2018), “Combining traditional teaching methods and PBL for teaching and learning of lean manufacturing”, *IFAC-PapersOnLine*, Elsevier, Vol. 51 No. 11, pp. 915–920, doi: 10.1016/j.ifacol.2018.08.465.

Trubetskaya, A., Manto, D. and McDermott, O. (2022), “A Review of Lean Adoption in the Irish MedTech Industry”, *Processes*, Multidisciplinary Digital Publishing Institute, Vol. 10 No. 2, p. 391, doi: 10.3390/pr10020391.

Wang, K.H., Wang, T.-H., Wang, W.-L. and Huang, S.-C. (2006), “Learning styles and formative assessment strategy: enhancing student achievement in Web-based learning”, *Journal of Computer Assisted Learning*, Wiley Online Library, Vol. 22 No. 3, pp. 207–217.

Yadav, D. (2022), “Criteria for good qualitative research: A comprehensive review”, *The Asia-Pacific Education Researcher*, Springer, Vol. 31 No. 6, pp. 679–689.

Yin, R. (2016), *Case Study Research Design and Methods*, 5th ed., Sage, Thousand Oaks, CA.