Effective learning method using extended reality: Digital TWI

Serkan Eren[1[0000-0003-4183-4733]] ✉, Eivind Reke[1] and Daryl John Powell[1[0000-0001-7224-2306]]

[1] SINTEF Manufacturing AS, Norway
serkan.eren@sintef.no
eivind.reke@sintef.no
daryl.powell@sintef.no

Abstract. Training within Industry was created under World War II by the U.S. Department of War, within the War Manpower Commission, to assist defense industries meet the high production output demand from less- or inexperienced labor. It ran from 1940 to 1945, made its way to Japan after the war and became a foundational component of the Toyota Production System (TPS). TWI is a well-proven lean education methodology consists of four main modules: Job Instructions (JI), Job Relations (JR), Job Methods (JM) and Program Development. This paper aims to explore combining TWI Job Instructions (JI) module with extended reality (XR) smart glasses and technologies that may create an effective and innovative lean education program.

Keywords: Lean, Training Within Industry (TWI), Education, Digitalization, Industry 4.0.

1 Introduction

Training within Industry, a well-proven lean education methodology, consists of four main modules and was developed during World War II by the U.S. Department of War to assist defense industries meet the high production output demand from less or inexperienced labor. A recent study of the impact on the organizations exposed to the TWI program revealed that companies who had received training had experienced a substantial gain in both productivity and sales year on year [1]. COVID-19 pandemic made difficult to meet in-person for many. Since March 2020, there has been a surge quest for remote access technologies [2]. This paper aims to explore combining TWI Job Instructions (JI) module with extended reality (XR) smart glasses and technologies that may create an effective and innovative lean education program. Even though TWI was designed as an in-person teaching method, a digital version of TWI method may remove the need of travelling to meet in-person and provide some further advantages related to re-training and onboarding. Conceptual research is exploited as framework and literature review is used as methodology. The paper is divided into 7 sections. The next section provides a theoretical background. Section 3 explains the research method used in this paper. Section 4 gives an overview over existing possibilities and examples of the combination of AR technologies and TWI, while a framework how combination of TWI and AR may contribute to the new industry era, industry 5.0 and the four concepts within this framework is suggested in Section 5. Discussions, conclusion, and suggestions for future work are presented in Section 6 and Section 7.

2 Background

2.1 Training Within Industry (TWI)

“If the worker hasn’t learned, the instructor hasn’t taught.” A key tenet to the Job Instruction method of Training Within Industry (TWI) emphasizes the importance of instructor’s responsibility [3]. The TWI Service developed and established in August 1940 by the National Defense Advisory Commission and was eventually placed under the Federal Security agency as a part of War Manpower Commission During World War II. Allied forces needed significant war supplies and TWI Service assisted war production industries to meet their manpower needs through a "train-the-trainer" program aimed at the supervisor level. Thereby enabling production to keep pace with war demands [4]. Foundation of the TWI were already laid at the beginning of World War I in US by Charles R. Allen, a vocational instructor from Massachusetts, when he developed his four-point method of Preparation, Presentation, Application, and Testing. The Emergency Fleet Corporation of the United States Shipping Board initiated a training program to increase the number of shipyard workers to 10 times the current number and Charles R. Allen’s method was used to train 500,000 people at the shipyards successfully [5]. The 4-step method formed the basis for the TWI programs developed over 20 years later.

Developing standardized programs that could meet the unique needs of various businesses, to neutralize the standard rejoinder that “our business is different”, was a challenge. To tackle this challenge, TWI explained first the purpose of the different modules, so-called the “J” programs by describing the five basic needs of supervisors: [6]

Knowledge of the work, Knowledge of responsibilities. Skill in instructing, Skill in improving methods, Skill in leading. TWI directly addressed the need for skills mentioned above through the three J courses: [7] Job Instruction (JI) Training on how to instruct employees, Job Methods (JM) Training on how to improve job methods, and Job Relations (JR) Training on how to lead people.

TWI service monitored six hundred companies during the service to measure the impact. The following percentage of plants reported at least 25% improvement in each of the following areas: [3]

Table 1. TWI Results in September 1945 [1]

Increased production	86%
Reduced training time	100%
Reduced labor-hours	88%
Reduced scrap	55%
Reduced grievances	100%

Although the Service was disbanded in 1945, millions of people in the USA, Canada, Great Britain, and Australia had already benefited from the programs and saw opportunity to share their knowledge with the rest of the world. Many of them formed consulting companies and continued to spread the TWI programs around the world, including, Japan, Italy, France, Spain, Belgium, Turkey, Indonesia, New Zealand, Ireland, Nepal, India, The Netherlands [8, 9]. Among all countries, TWI has indeed had a strong influence in Japan. Until 1992, TWI usage dropped off in Unites States, while it was used heavily in Japanese companies. Toyota started to use TWI programs in 1951 and became the backbone of Toyota's standardization philosophy [7, 10].

Four steps of Job Instruction

According to Graupp and Wrona [11], showing alone or telling alone to instruct employees is not effective, even though they are important elements of instructing. Job Instruction is a method to get a person quickly remember how to do a job, correctly, safely and conscientiously. [9] Graupp and Wrona [11] claims that the JI 4-Step Method, when applied properly, can assure a successful training experience every time. The JI 4-Step Method is illustrated in Figure 1.

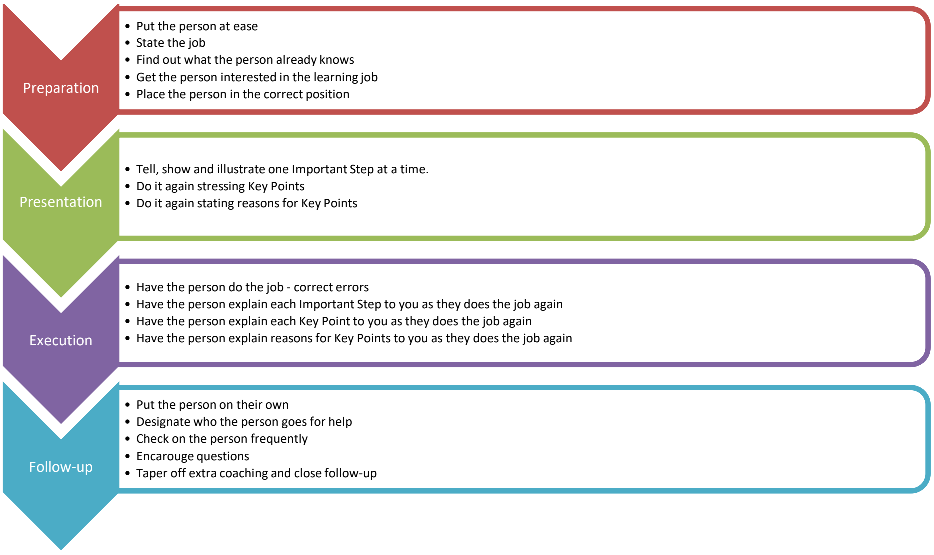

Fig. 1. Four steps of Job Instruction [11]

The first step is about preparing the employee for training. At this step, it is crucial to make the trainee comfortable, understand the knowledge state of the trainee and create an interest in the learning job. The second step is where the job is introduced and explained in detail. This step is where instructor tell, show, and illustrate each important step at a time and repeat with underlining the Key Points and the reasons for Key Points again. Third step is the execution step for the trainee. Trainee performs the job and repeat with explaining Key Points, and then repeat again with the reasons for Key Points, as the instructor did on the previous step. Finally, on the fourth step, the main duty of the instructor is auditing the trainee at fixed interval.

2.2 Extended Reality (XR)

The term extended reality (XR) is an umbrella term that often used as a generic expression covering both augmented reality (AR) and virtual reality (VR) [12]. Milgram's Reality-Virtuality Continuum, spans between the real environment and the virtual environment comprise Augmented Reality and Augmented Virtuality (AV) in between, locates AR closer to the real world [13].

Augmented Reality (AR) refers to a live view of physical real-world environment whose elements are merged with augmented computer-generated images creating a mixed reality [12]. It is a combination of digital information with the real world that is presented in real-time [13–15]. According to Azuma [14], AR as systems combine real and virtual, are registered in 3-D and interactive in real time. The concept of augmenting the view of the world has mentioned already in 1901 by L. Frank Baum in his novel "The Master Key" [16]. Even though the concept of AR dates back to the 1950s [17], AR phrase is considered to have been coined by Tom Caudell and David Mizell in 1990 to describe how the head-mounted displays used by electricians when assembling complicated wiring harnesses worked at Boeing [18]. Augmented Reality (AR) was perceived as science fiction for decades until it had its mainstream breakthrough when 21 million gamers used an AR smartphone game within one week after the release [19]. In recent years, the advancement of computer technologies motivated researchers to develop new ideas and uses for AR [20].

3 Research method

In this research paper, we adopt a conceptual research framework, as presented by Crawford [21], wherein research is conducted by observing and analyzing already present information. We attempt to establish an argument for the importance of the study, underline the relationships among who and what will be studied and finally demonstrate the alignment among concept, trends, and findings with our framework that is presented in Section 5 [22, 23]. We use secondary qualitative data and literature review as main research methodology. We developed a literature review in the Google Scholar in the period 1990 to 2022. The question and sub-questions that guided this review were as follows: "Is the combination of extended reality and TWI used as a learning/instructional method?" and from this question: "What type of products/factories mostly benefit from this combined learning method?", "What are the advantages of the method based on gained experiences?", "What are the disadvantages and/or obstacles based on experiences?", "What are the trends for TWI and combination of TWI and XR?"

The string used was "training within industry" AND "augmented reality". These were searched in title, abstract, and keywords for the period from 1990 to the present.

The outcome of this conceptual paper is planned to be tested on a case study after this paper is published.

4 Findings

Our literature search on Google Scholar gave 51 related results related to “training within industry” and “augmented reality” while a search on Google with the same phrases resulted in about 3160 results where most of the results were not related to the concept of combining them since results were containing two phrases independently. Date of the articles on the internet indicates a rising trend on virtual training solutions (not necessarily combined with TWI) in the recent years. This trend may be related strongly to the COVID-19 pandemic and subsequent workforce disruptions which have created and/or strengthen challenges in employee recruitment/retention and training without local presence areas in the industry worldwide. Based on a Manufacturing Institute and Deloitte study, the National Association of Manufacturers estimates that manufacturers will need to fill 4.6 million jobs by 2028 [24]. Out of this 4.6 million jobs, the operators are the most flexible part of the production system and they have to be prepared for increasing complexity [25]. Thus, an effective learning method assisted with AR technology may contribute to face these challenges.

4.1 Examples from the literature

In our research, we have found many examples of virtual reality (VR) applications combined with TWI for training purposes in the industry. It is tested and evaluated in companies in automotive and aerospace industry mainly. Scania in Södertälje, Sweden tested and evaluated virtual training based on TWI Job Instruction methods and found the method promising even though the study did not result in any greater improvements [26]. Bernhartz and Malis’s [25] study on workflow for virtual training for assembly of the bogie cross member at Volvo GTO in Tuve Plant in Göteborg, Sweden reveals that virtual training cannot fully replace the current training practices, but can act as a support to ease the cognitive load. Numerous use cases, applications indicates that VR training within industry have been tested out and used widely in the industry. The next leap in innovative training is incorporating augmented reality where a user can see the real-world environment around them with an overlay of instruction through an AR device, including checklist items for a first time student performing a task or allow a senior technician to provide remote assistance to a less experienced technician [27]. Even though there are challenges in application, pioneering organizations, such as Amazon, Facebook, General Electric, Mayo Clinic, and the U.S. Navy, are already implementing AR and seeing a major impact on quality and productivity [28].

The BMW Group (2019) was the first major company to implement AR into their assembly employee training. Through AR in assembly training, one tutor becomes capable of training three trainees with the same outcome quality, instead of one-to-one teaching. Thus, personnel need for assembly training can get reduced [29].

At Boeing, AR was used to guide trainees through the 50 steps required to assemble an air-craft wing section involving 30 parts, resulted in 35% reduced time in completion of work compared to traditional 2-D drawings and documentation. In addition, the number of trainees with little or no experience who could perform the operation correctly the first time increased by 90%. Thus, AR training has had a dramatic impact on the productivity and quality of complex aircraft manufacturing procedures [30].

Newport News Shipbuilding (NNS) was an early adopter of the TWI programs during WWII and is now enhancing its effectiveness by coupling TWI principles with augmented reality application coined “Augmented TWI”. Since 2007, they have explored Augmented Reality as a means to shift away from paper-based documentation in the work environment [31]. With AR, they can now see the final design superimposed on the ship, which reduces inspection time by 96%—from 36 hours to just 90 minutes. Overall, time savings of 25% or more are typical for manufacturing tasks using AR [28].

Implementation of augmented reality to train unskilled operators on a busbar bending process resulted in easier achievement of the task [32]. General Electric (GE) achieved an increase in productivity and efficiency by applying AR [33]. Honeywell also improved its operator training by implementing AR [32]. DHL’s need for traditional instructors is reduced while the onboarding speed for new employees is increased by providing AR real-time training [28]. The TWI Institute announced a partnership with Dozuki, an industry leader in standard job instruction software. Companies aim to provide personalized, one-on-one instructions with strong visual guides. Expected outcome is that learners can use Dozuki guides as references and “memory joggers”, since they can mirror the Job Instruction Breakdowns used in TWI training [34]. An empirical analysis from Loch [35] compared video instruction with a screen-based augmented reality assistance for a LEGO assembly task with 27 steps. Results of the study indicate a lower completion time, significantly less number of errors and a lower mental workload for the students trained by means of the augmented reality application. Finally, Chen [36] suggests a framework for the application of artificial intelligence (AI) technology to training and managerial challenges ,which can be applied to the training process, including knowledge management (KM), needs analysis, training organization, and results feedback.

5 Framework for Digital TWI

Use cases and examples from the industry on implementing AR technologies for training purposes given in Section 3 shows that skill improvement, onboarding processes may benefit from this technology in many ways. In this section, we suggest a framework for applications of augmented reality assisted TWI, so-called “Digital TWI”. The framework consists of four concepts are described later in this section: 1) AR-enhanced Job Instruction - augmented TWI (ATWI), 2) Remote Job Instruction - remote augmented TWI (RTWI), 3) Retraining Job Instruction - assisted with instructor on demand (RJI), and 4) Self-training Job Instruction - assisted with instructor (SJI).

These suggested concepts differ from each other with their area of usage and the presence of instructor as shown in Table 2. As mentioned in 1.1, instructor's responsibility is crucial for a successful training according to TWI. Therefore, each concept suggested in this framework does include local or remote presence of the instructor, either all the time, partially or on demand.

Table 2. Digital TWI concepts

Concept	Area of usage	Instructor presence
AR-enhanced JI	onboarding, internal training, retraining	local presence
Remote JI	onboarding, internal training, retraining	remote presence
Retraining JI	retraining	local and/or remote on demand
Self-training JI	onboarding, internal training, retraining	local and/or remote partially

5.1 AR-enhanced Job Instruction

This concept is the closest method to the traditional TWI, where instructor and trainee are physically in the same place. Trainee is equipped with AR/XR smart glasses. Ideally, instructor can control the flow of the content on trainee's smart glasses. If this is not possible, it is also sufficient that instructor can see the progress of the trainee on another screen, or maybe on his own AR glasses. In this way, instructor still controls the flow of the training while trainee gets visual aids and feedbacks through the AR smart glasses. Finally, the training session may be recorded. Thus, recorded session may be used to review the session by going through together with the trainee.

This concept combines the advantages of both TWI method and AR capabilities. The local presence and guidance of the instructor all the time maintain the most important element of the training, namely the teacher. The drawback of this concept is that it requires a presence of an instructor all the time. To overcome this disadvantage, an instructor may teach more than one trainee simultaneously. However, the efficiency of training groups should be studied. AR-enhanced JI may be used in any kind of training at any phase of an employee, from onboarding to retraining.

5.2 Remote JI

This concept is similar to the AR-enhanced JI, with one big difference; the instructor is not locally present. Ideally, instructor has his/her own AR and can control the flow of the training remotely. It is advantageous that instructor can also see what the trainee does and/or see simultaneously. This will give a better picture of the situation of the trainee to the instructor. Thus, instructor can give better feedback through the training. Again, group training may be possible, but it is anticipated that it will be even less efficient than previous method, due to the fact it will be more difficult to have an overview of many people at the same time for the instructor remotely.

The most important advantage of this concept is undoubtedly that the instructor and the trainee does not have to be in the same place. Especially COVID-19 pandemic showed us recently that industry requires such remote solutions. In some areas it is also approved that using AR may improve the productivity by decreasing operators' error

[32]. Like AR-enhanced JI, remote JI may be suitable for any kind of training in a company at any phase of an employee, including onboarding, internal training, and retraining.

5.3 Retraining JI

This concept is ideal for an employee that has already been taught by using AR-enhanced JI or Remote JI as explained above. It requires that the training session is recorded earlier. If an employee needs to refresh his/her skills, it may be possible to use this recorded material to retrain the employee. Even though this method may sound like a traditional video on demand training, there is a still big difference compared that the training material that was recorded earlier is unique to the employee. Thus, it will be easier to remember for the employee the training session. As mentioned earlier in this section, we always chose to include the instructor on any training method suggested in this framework. For this concept, we suggest that the instructor may be available on-demand and/or for the final review. Thus, there will be minimal resource need of the instructor which is the biggest advantage of this concept. As the name implies, this concept is meant to be used at retraining and refreshing skills cases in the company.

5.4 Self-training JI

This concept is an attempt to generate a more generic (but not full) training material and method for the employees. Even though TWI underlines that every trainee is unique, and training should be applied individually, some (or maybe even most) of the training steps may be common. By generating a generic digital training material which can be followed with AR glasses, it may be possible to train employees. Partially presence (either local or remote) of the instructor may ensure personal and unique training. Finally, it may be also suggested to prepare variations of the training programs so that the instructor may choose to offer different variations of the training to the trainees. Similar to Blended Learning [37], self-training JI may also represent some combination of face-to-face and online (remote) learning. This concept may be suitable for any kind of training at any phase of an employee and may have an advantage of reducing the instructor resourced need for training tremendously. However, it requires resource and investment for generating/supporting training materials.

6 Discussion and conclusion

Section 4 reveals that there many possibilities available by combining TWI method with AR technologies. In this section, we discuss why JI is only chosen among all TWI methods, and the maturity and ease-of-use of the method and technology. Finally, we conclude our paper by summarizing some of the generic advantages and the challenges, mainly based on literature.

As described in 1.1, TWI service consists of three J courses, namely Job Instruction (JI), Job Methods (JM) and Job Relations (JR). In this paper, we choose to combine only Job Instruction with AR, due to the following arguments: JI is often the first TWI method that is used in companies and is the most used method of TWI Service. JI is a method for effective training and AR solutions are tested/evaluated heavily for training purposes. Preparation for visual aids/instructions may be very complex for Job Methods since it may involve heavy technical discussions, etc. and finally, there is minimal need of visualization for Job Relations.

By looking at JI method and AR technology separately, we can conclude that JI is an old and well-proven method that was used worldwide. The method is not much in-development. In most companies that use JI, the original documents from World War II are still used. Mostly, the method is adapted, rather than further developed. AR technologies have been in development and still under development heavily. The technology is in use in many companies worldwide. Thus, we may conclude that the technology is mature enough to be used on the market. Authors of this paper predict that this development will continue rapidly and will create new possibilities and features.

It is very crucial that a method and/or technology is easy enough to be accepted by users. We summarize our conclusions on ease-of use of JI and AR in this section. JI is based on four simple steps, explained in 1.1.1. The four-step method makes the JI easy to remember and easy to implement. As an instructor that wants to learn JI, it takes only 10 hours session and some practice. JI pocket card eases even more the process, since they can be carried all the time in case steps are forgotten. AR may be challenging to use for some at the beginning. As like all other technologies gadget, using AR solutions may be difficult for some individuals more than others. Thus, training of the technology use in advance may be required. Updates/changes in hardware/software may create new challenges, which may require retraining for the technology.

The study also found some advantages of combining TWI and AR, mainly based on literature and state-of-the-art in the industry. Augmented reality type visualization levelling out performance difference by giving more support to inexperienced workers than experienced [38]. Despite of advancements in intelligent automation, humans/operators still have an essential role in manufacturing operations [32]. JI can be a resource intensive process since it requires one person responsible to teach each operator during learning [39]. Combining it with AR and using the concepts that are suggested in Section 4, resource need may be minimalized. Learning the skills to carry out a set of tasks can only be obtained through learning-by-doing and this learning action should be at the "Gemba"-the real place instead of in the classroom [40]. AR can provide the information right at the workplace [34]. Furthermore, they can be trained step-by-step to a work process without causing serious damage [41]. Further training or retraining is useful in order to bring employees back to less frequent process steps as needed [42, 43]. AR training allows location-independent training attuned to the individual learning curve [37]. Particular errors that are repeated by operator may be eliminated by providing tailored instructions and repeat the training [28]. Due to the fact that our brain matter is mostly dedicated to vision (30 to 50% opposed to 10% to touch, and only 3% to hearing), any visual information is processed seamlessly and unconsciously [44]. Using AR-enhanced training may provide an effective job instruction method, since it is mainly driven by visual aids. According to Powell and Reke, lean Production can be reframed as a learning system and lean thinking is not possible without learning [45, 46]. Therefore, it is crucial to establish and implement an effective learning method based on a well-proven lean learning method JI, especially for the companies want to cultivate a lean culture within their organizations.

There are also some disadvantages and challenges associated with JI and AR. Investment costs of AR technologies can be high. Continuous development of AR digital materials may be needed. This will add another cost for the training. Support for the technology may be needed, which adds another cost. AR technology may not be accepted by some of the users. According to Syberfeldt, Danielsson, Holm, and Wang [47], key factors to improve the acceptability of AR systems are as follow: 1) Identify tasks of high enough complex so that the user to feel that it is worth using the AR system. 2) Ensure improved efficiency so that the user see meaning in using it. 3) Aim for a perfect system so that imperfections do not create skepticism. 4) Emphasize the advantages so that the new users of the technology will "buy" it easily. Finally, JI method may be perceived as outdated, old method, which may decrease the user acceptance.

Implementing new technologies and methods in an organization may be challenging. Bernhartz and Malis [25], summarized challenges in virtual training as follow: 1) Usability – training system should be adapted to the users and be intuitive since users may have various experience and backgrounds with technology. 2) User acceptance – users should be engaged already in the development phase to minimize skepticisms. High acceptance is a key factor for AR technology [47]. 3) Cybersickness – a complex issue that is hard to prevent, resulting in nausea and headache, especially for VR system. IT should be evaluated whether this can be a challenge for AR or not.

These challenges may be present for AR-enhances solutions as well. Therefore, it is beneficial to think about possible countermeasures to overcome these challenges, especially in designing phase of the training program.

7 Conclusion and suggestions for further research

This paper presents a framework with four main concepts that attempts to combine TWI Job Instruction method with extended reality technologies. We conclude that it is worth to empirically validate the concepts in real-world use cases since it can provide an efficient learning method that increases productivity and operator's flexibility while it decreases the cost of training and the operator's error. For future research, we suggest an empirical research based on a real-world case. The framework and the concepts that are introduced in Section 5 may be tested on real use case studies and the results may be evaluated. Critical success factors for the concepts should also be evaluated.

8 References

1. Bianchi, N., Giorcelli, M.: The Dynamics and Spillovers of Management Interventions: Evidence from the Training Within Industry Program. Journal of Political Economy. 130, 1630–1675 (2022).

2. Netland, T., Hines, P.: Teaching in Virtual Reality: Experiences from a Lean Masterclass. In: European Lean Educator Conference. pp. 155–162. Springer (2021).
3. Service, U.S.T.W.I., Training, U.S.W.M.C.B. of, Kirkpatrick, F.: The Training Within Industry Report, 1940-1945: A Record of the Development of Management Techniques for Improvement of Supervision, Their Use and the Results. War manpower commission, Bureau of training, Training within industry service (1945).
4. Huntzinger, J.: The roots of lean.
5. Roser, C.: All about lean, https://www.allaboutlean.com/training-within-industry/.
6. Graupp, P., Wrona, R.J.: Implementing TWI: Creating and managing a skills-based culture. Productivity Press (2018).
7. Robinson, A.G., Schroeder, D.M.: Training, continuous improvement, and human relations: the US TWI programs and the Japanese management style. California Management Review. 35, 35–57 (1993).
8. Dinero, D.A.: Training within industry: The foundation of lean. Productivity Press New York (2005).
9. Dinero, D.A.: The TWI Facilitator’s Guide: How to Use the TWI Programs Successfully. Productivity Press (2016).
10. Liker, J.K.: Toyota way: 14 management principles from the world’s greatest manufacturer. McGraw-Hill Education (2004).
11. Graupp, P., Wrona, R.J.: The TWI workbook: essential skills for supervisors. CRC Press (2017).
12. Furht, B.: Handbook of augmented reality. Springer Science & Business Media (2011).
13. Paul Milgram, Haruo Takemura, Akira Utsumi, Fumio Kishino: Augmented reality: a class of displays on the reality-virtuality continuum. Presented at the Proc.SPIE December 21 (1995). https://doi.org/10.1117/12.197321.
14. Azuma, R.T.: A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments. 6, 355–385 (1997). https://doi.org/10.1162/pres.1997.6.4.355.
15. Feiner, S., MacIntyre, B., Haupt, M., Solomon, E.: Windows on the world: 2D windows for 3D augmented reality. In: Proceedings of the 6th annual ACM symposium on User interface software and technology. pp. 145–155 (1993).
16. Baum, L.F.: The Master Key, an Electrical Fairy Tale. Bottom of the Hill Publishing (2014).
17. Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., Ivkovic, M.: Augmented reality technologies, systems and applications. Multimedia tools and applications. 51, 341–377 (2011).
18. Berryman, D.R.: Augmented reality: a review. Medical reference services quarterly. 31, 212–218 (2012).
19. Serino, M., Cordrey, K., McLaughlin, L., Milanaik, R.L.: Pokémon Go and augmented virtual reality games: a cautionary commentary for parents and pediatricians. Current opinion in pediatrics. 28, 673–677 (2016).
20. Heidler, N.: Intelligent Augmented Reality Assembly Training.

21. Burkholder, G.J., Cox, K.A., Crawford, L.M., Hitchcock, J.H.: Research design and methods: An applied guide for the scholar-practitioner. Sage Publications (2019).
22. Jozkowski, A.C.: Reason & Rigor: How Conceptual Frameworks Guide Research, 2nd Edition (2017). Occupational Therapy In Health Care. 31, 378–379 (2017). https://doi.org/10.1080/07380577.2017.1360538.
23. Miles, M.B., Huberman, A.M., Saldaña, J.: Qualitative data analysis: A methods sourcebook. Sage publications (2018).
24. The Manufacturers' Guide to Finding and Retaining Talent, https://www.nist.gov/system/files/documents/2022/05/26/Manufacturers_Guide_to_Finding_and_Retaining_Talent_WEB.pdf, (2022).
25. Bernhartz, H., Malis, L.: Workflow for training in virtual reality, (2019).
26. Augustsson, N., Löfström, H.: Evaluation of the virtual training softwares SeQualia and Vizendo, (2017).
27. Bringing technology to today's Air Force, https://www.travis.af.mil/News/Commentaries/Display/Article/1859305/bringing-technology-to-todays-air-force/, last accessed 2022/07/07.
28. Michael E. Porter: Why Every Organization Needs an Augmented Reality Strategy, https://hbr.org/2017/11/why-every-organization-needs-an-augmented-reality-strategy.
29. Group, B.M.W.: Absolutely real: Virtual and augmented reality open new avenues in the BMW Group Production System, https://www.press.bmwgroup.com/global/article/detail/T0294345EN/absolutely-real:-virtual-and-augmented-reality-open-new-avenues-in-the-bmw-group-production-system?language=en, (2019).
30. Porter, M.E., Heppelmann, J.E.: Why every organization needs an augmented reality strategy. HBR'S 10 MUST. 85, (2017).
31. Next generation skilled workers using augmented reality | Association for Manufacturing Excellence, https://www.ame.org/target/articles/2016/next-generation-skilled-workers-using-augmented-reality, last accessed 2022/07/09.
32. Na'amnh, S., Miklós Daróczi, I.H.: Implementing the Augmented Reality as an Industry 4.0 Application to Simplify the Busbar Bending Process during the Covid-19 Pandemic. Transactions of FAMENA. 45, br. 3, 115–125 (2021). https://doi.org/10.21278/TOF.453026921.
33. Smart Specs: OK Glass, Fix This Jet Engine | GE News, https://www.ge.com/news/reports/smart-specs-ok-glass-fix-jet-engine, last accessed 2022/07/09.
34. Graupp, P.: New Partnership: TWI Institute & Dozuki, https://www.twi-institute.com/twi-dozuki/, last accessed 2022/07/11.
35. Loch, F., Quint, F., Brishtel, I.: Comparing video and augmented reality assistance in manual assembly. In: 2016 12th International Conference on Intelligent Environments (IE). pp. 147–150. IEEE (2016).
36. Chen, Z.: Artificial Intelligence-Virtual Trainer: Innovative Didactics Aimed at Personalized Training Needs. Journal of the Knowledge Economy. 1–19 (2022). https://doi.org/10.1007/s13132-022-00985-0.

37. Powell, D.J., Vries, M. de, Roij, M. van, Slomp, J.: Blended Network Action Learning–A Digital Lean Approach to Solving Complex Organizational Problems Across Space and Time. In: European Lean Educator Conference. pp. 213–224. Springer (2021).
38. Kurdve, M.: Digital assembly instruction system design with green lean perspective-Case study from building module industry. Procedia CIRP. 72, 762–767 (2018). https://doi.org/10.1016/j.procir.2018.03.118.
39. Liker, J.K., Meier, D.: Toyota way fieldbook. McGraw-Hill Education (2006).
40. Reke, E., Powell, D.: Rethinking value–a means to end the whispering game. Procedia CIRP. 104, 1041–1045 (2021).
41. Makris, S., Karagiannis, P., Koukas, S., Matthaiakis, A.-S.: Augmented reality system for operator support in human–robot collaborative assembly. CIRP Annals. 65, 61–64 (2016).
42. Kroeker, K.L.: Mainstreaming augmented reality. Communications of the ACM. 53, 19–21 (2010).
43. Peddie, J.: Augmented reality: Where we will all live. Springer (2017).
44. Ballé, M., Chartier, N., Coignet, P., Olivencia, S., Powell, D., Reke, E.: The lean sensei. The Lean Enterprise Institute Inc., Boston (2019).
45. Powell, D., Reke, E.: No Lean Without Learning: Rethinking Lean Production as a Learning System. In: Ameri, F., Stecke, K.E., von Cieminski, G., and Kiritsis, D. (eds.) Advances in Production Management Systems. Production Management for the Factory of the Future. pp. 62–68. Springer International Publishing, Cham (2019).
46. Netland, T.H., Powell, D.J.: The Routledge companion to lean management. Routledge (2016).
47. Syberfeldt, A., Danielsson, O., Holm, M., Wang, L.: Visual Assembling Guidance Using Augmented Reality. Procedia Manufacturing. 1, 98–109 (2015).