

Using Augmented Reality and Learning Factories to Deliver Effective Manufacturing Training Programs

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Abstract. Augmented reality (AR) holds great promise in revolutionizing training methodologies across diverse fields, particularly in manufacturing. This paper proposes a morphology to support the integration of AR into learning factories, creating a symbiotic relationship that enhances training effectiveness and efficiency. The morphology introduces key characteristics such as target group, purpose, reality environment, technology, space, assessment, and system integration, tailoring AR applications to the specific needs of manufacturing training programs. The incorporation of AR within learning factories revolutionizes traditional pedagogical approaches. In addition, it enables realistic simulations, multi-sensory experiences, and remote collaboration between the different stakeholders involved. The paper offers a perspective on the value of AR as a tool in manufacturing training programs for knowledge development and skills acquisition. It emphasizes the importance of maintaining a balance between AR and traditional hands-on training, ensuring pedagogical alignment, considering ethical implications, and evaluating the sustainability and cost-effectiveness of AR integration in manufacturing education. Despite some challenges, the paper underscores the substantial benefits of AR in manufacturing training, heralding a transformative era in skill acquisition and knowledge transfer within the industrial landscape.

Keywords: Augmented Reality, Learning Factory, Manufacturing, Training.

1 Introduction

Augmented Reality (AR) has emerged as a promising technology with applications for training in various fields, including healthcare, engineering, and manufacturing [1]. Traditional training methods in manufacturing often rely on classroom-based learning or hands-on practice. However, these methods may not adequately prepare trainees for real-world challenges and technical complexities. Although augmented reality has been used within manufacturing processes, there is a limited application in the delivery of training programs for manufacturing [1–3]. As such, there is a need for a different approach to training in manufacturing that builds on the capabilities of AR and combines it with the concept of learning factories. The ability of AR to integrate virtual objects

into the real environment makes it a valuable tool for enhancing learning experiences. Such an ability coupled with the concept of learning factories provides an environment where trainees can gain practical and hands-on skills more efficiently. Learning factories can be used along with AR for simulating real manufacturing scenarios and tasks, allowing trainees to learn in a safe and controlled environment before transitioning to the actual production floor [4]. The combined approach to training, not only enhances the learning experience but also improves the efficiency and effectiveness of manufacturing processes [2]. By incorporating AR into learning factories, trainees will experience a more immersive and interactive learning environment compared to the standalone use of the technology on its own. This improves the trainees understanding of complex manufacturing processes and enhances their problem-solving skills. This paper proposes an extension to the learning factory morphology, proposed by Abele et al. [5], and includes key characteristics and attributes that are essential considerations when deploying augmented reality into the learning factory environment.

2 Literature Review

AR describes a mediated reality, where actual and virtual elements converge to craft an immersive experience that seamlessly blends the tangible and digital worlds [6]. It can be deployed within learning factories to enrich the dissemination of knowledge and skills [7]. A pivotal feature of AR that amplifies its potential in learning factories is its ability to visually represent digital data in conjunction with real-world machinery, processes, production systems, and products [8]. The integration of digital content with the physical world can significantly enhance comprehension of processes, data, methodologies, and systems. This allows users to engage in learning scenarios that might be prohibitively expensive, perilous, or complex to conduct exclusively within a real-world environment due to the AR's capacity to extend the spatial, temporal, and functional dimensions of a physical learning factory. Therefore, enhancing the learning experience of the trainees. AR introduces innovative approaches for instructing learners and imparting knowledge and skills, not limited to visual cues, but also encompassing auditory and other natural user interfaces [9]. Moreover, given that learning environments blend pedagogical methods with technology, learning factories present a promising arena for honing AR competencies. This enables learning factories to serve as ideal settings for acquiring proficiency in understanding AR potentials, applications, and implementation in an industrial context [4]. Ultimately, learning factories offer an exceptional environment for understanding the capabilities of AR within an industrial context, enabling hands-on experience with development methodologies, necessary tools, and hardware devices. Compared with Virtual Reality (VR), AR does not aim to replace the real world with a simulated one. Consequently, it is often classified as a Mixed Reality (MR) system [2]. Fig. 1, provides a continuum that spans from wholly real environments (reality) to entirely virtual ones (virtuality). Within this spectrum, mixed reality environments fuse elements from both realms, with the proportion of virtual components increasing from left to right. An application situated towards the reality end is classified as 'augmented reality', while one leaning towards the virtuality end

is termed ‘augmented virtuality’ [8]. There are various technological approaches that fall along the reality-virtuality continuum. Tangible interfaces employ physical objects to generate virtual models. In Spatial AR, virtual objects are integrated into the user's actual surroundings. Holographic spatial AR permits a greater prevalence of virtual objects and deeper user engagement. Semi-immersive VR is closely tied to the virtual environment, emphasizing virtual objects over real ones, whereas in immersive VR, the user is immersed in an environment that is predominantly virtual [10].

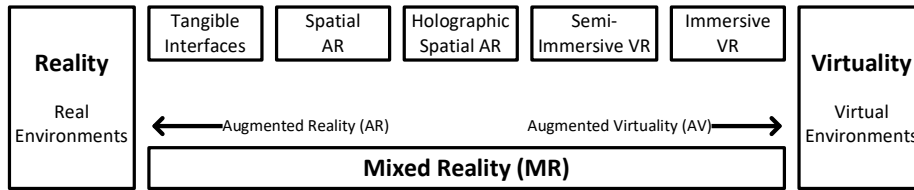


Fig. 1. Mixed Reality Continuum [10]

3 Training for Manufacturing

AR has shown significant potential in the field of education and training, offering an immersive and interactive learning environment that can transform the way we approach learning [1, 3, 6, 9]. It has been particularly effective as a training tool in manufacturing sectors, especially in manual assembly procedures [11]. In the context of learning factories and manufacturing training programs, AR can provide realistic simulations of real-life scenarios, allowing learners to practice and develop their skills in a controlled environment. This interactive approach can enhance engagement and retention, providing learners with a more engaging, effective, and cost-efficient learning experience. Applications can virtually expand the physical infrastructure within a learning factory, with machines being enhanced with virtual components showcasing diverse configurations, thereby removing the need for actual hardware investments and setup times [12]. For example, product variations can be simulated without the requirement for physical prototypes, and scenarios such as process breakdowns or emergencies can be simulated within a safe environment for training appropriate responses. The overlay of digital information onto the physical world enhances the perception of reality, thereby supporting experiential learning. Experiential learning is a pedagogical approach that enables learners to acquire practical skills and competencies by engaging in authentic tasks and reflecting on their performance [13]. This approach has been identified as a critical component in competency-based education and challenge-based learning environments such as manufacturing [2]. AR also enhances multi-sensory training, a learning method that stimulates multiple senses of the learners, such as vision, hearing, and touch. The use of multi-sensory technology creates a rich and immersive learning experience that improves learner engagement and retention of the material [14]. Moreover, by broadening the spatial perspective, AR transcends the physical confines of a learning factory into the manufacturing ecosystem. In that regard, AR can promote remote collaboration among users and learners, facilitating the understanding

and experience of concepts like supply chain flows, environmental impacts, and new product design and/or development. However, the integration of AR in learning factories presents several challenges [6, 12] related to information and cognitive overload, lack of experience, resistance from trainers, complex and costly technology. Despite these challenges, the potential benefits of AR in learning factories for training are substantial, and it can be a powerful tool for enhancing the trainees' learning experience.

3.1 Morphology Extension: AR & LF in Manufacturing Training

Studies of the AR technology in the manufacturing industry [2, 15] have highlighted that the reality environment and the type of technology being employed are some of the main elements for a successful interaction, as well as the mode of usage whether that is physical, virtual, or hybrid. In other studies on the effect of AR applications in the learning process, it was found that the purpose and approach of how the learners are being assessed are essential criterion that also need to be considered [16, 17] by the trainers. In recent years, research studies have published frameworks focused on the use of AR in learning factories [4, 7]. The proposed morphology extension in this paper focuses on the requirements for manufacturing training to be effective. The morphology presented in Fig. 2 borrows existing attributes [5] and proposes 5 new key characteristics along with their defined attributes. The key characteristics are target group, purpose, reality environment, technology, space, assessment, and system integration.

Dimension	Characteristic	Attributes				
Augmented Reality	Target Group	Beginner		Experienced		
	Purpose	Acquire new skill	Advance existing skill	Understanding key concepts		
	Reality Environment	Augmented Reality			Augmented Virtuality	
	Technology	Tangible interfaces	Spatial AR	Holographic spatial AR	Semi-immersive VR	Immersive VR
	Space	Physical	Hybrid	Virtual		
	Assessment	Formative		Summative		None
	System Integration	None	Partial	Full		

Fig. 2. Extended morphology for using AR in LF for manufacturing training

The purpose and the learning outcomes of the manufacturing training program will be defined based on the specific needs of the target group, according to whether they are beginners or experienced, interested in knowledge or skills development. This could include understanding key concepts in manufacturing (i.e. lean manufacturing), developing practical skills in using AR technology, and applying these skills in a learning factory environment. The learning outcomes from the training program can be assessed using summative or formative methods [18], or not assessed at all. The technology available and used, along with the purpose of the training directs towards the reality environment more suited for use, which can range anywhere on the continuum between augmented reality and augmented virtuality [10]. This includes decisions related to AR

hardware such as headsets or smart glasses, and software for creating and interacting with AR content. The choice of technology will depend on the specific requirements of the training program. The training program can make use of either physical, or virtual spaces, or even a hybrid environment. The physical space will be the LF where learners can apply their skills in a realistic environment, whereas the virtual space will not require the presence of the physical learner, such as in the cyberlearning factory [4]. The AR technology could be used as a standalone approach within the learning factory, or it could be integrated with other learning systems used, such as material flow tables, simulation tools, 3D printing technologies, workstations, etc. Full integration will allow for a seamless learning experience, where learners can apply their skills in a variety of contexts and in numerous work situations. An example of how this morphology can be applied teaching the concepts and tools of lean manufacturing to undergraduate students is by making choices for each of the characteristics. The choices made could be: The students are beginners whose purpose is to understand a key concept, this will be done in an augmented reality environment deploying spacial AR. The students will be physically present in the learning factory and will only be assessed formatively. The AR system used will not be integrated with other technologies in the learning factory. However, the proposed morphology will need to be verified and validated through a use case, such as developing a training on the concepts and tools of lean manufacturing, which is suggested as a future research point.

4 Discussion

The integration of AR within learning factories in manufacturing training, as explored in this paper, represents a shift from traditional pedagogical approaches; the following discussion points represent essential considerations for its success.

The Efficacy of Augmented Reality in Manufacturing Training. AR's potential to transform learning experiences into immersive, interactive sessions undeniably offers a novel dimension in skill acquisition and knowledge transfer. However, the effectiveness of AR in manufacturing training is contingent upon the complexity of the learning tasks, the available technological infrastructure, and the adaptability of learners to this mode of instruction. While AR can simulate real-world scenarios with remarkable fidelity, there is an inherent risk of creating a learning environment that is overly reliant on virtual elements and devoid of psychological safeguarding that can be achieved through peer-to-peer interaction. Such risk of over-reliance could potentially lead to a disconnect from actual manufacturing environments, where unpredictability and variability play a crucial problem-based learning role. Therefore, it is imperative to strike a balance where AR complements traditional hands-on training, ensuring that learners are equally prepared for the tangible challenges of real-world manufacturing [19].

Challenges in Implementing AR in Learning Factories. The deployment of AR in learning factories is fraught with challenges that extend beyond the technological realm [20]. One of the primary barriers is the cost associated with implementing AR

technology, which includes not only the initial investment in hardware and software but also the ongoing expenses related to testing, validation, maintenance and updates. Additionally, the complexity of AR systems necessitates specialized training for instructors, which can be a resource-intensive process. Resistance to the adoption of AR technology is another significant challenge, particularly from trainers and learners accustomed to conventional training methods. This resistance may stem from a lack of familiarity with AR technology, lack of endorsed use-cases and apprehension about overall efficacy. Overcoming this resistance would require a concerted effort to demonstrate the safety and tangible benefits of AR in enhancing the learning experience.

Balancing Technological Advancements with Pedagogical Needs. In the realm of manufacturing training, the advent of AR technology presents an opportunity to enhance pedagogical methods. However, this technological advancement should not overshadow the fundamental objectives of education and skill development [21]. The focus must remain on how AR can serve as a tool to facilitate learning, rather than becoming the centerpiece of the educational experience. This balance is crucial to ensure that the technology serves the pedagogical needs and not the reverse.

Prospects and Ethical Considerations of AR in Manufacturing Education. Looking into the future, the role of AR in manufacturing education appears promising, in combination with Large Language Models (LLMs) as technology that could offer new avenues for individualised immersive instruction and learning. This optimism needs to be tempered and informed with a commitment to ongoing research and development to ensure that AR-based training remains relevant and effective. Additionally, ethical considerations, particularly concerning data privacy and the psychological impact of prolonged exposure to AR environments, warrant careful consideration. These ethical dimensions are as crucial as the technological and pedagogical aspects and must be addressed to ensure the responsible deployment of AR in educational settings [22].

Sustainability and Cost-Effectiveness of AR in Training Programmes. The sustainability and cost-effectiveness of integrating AR into manufacturing training programmes are critical factors that merit exploration. While AR has the potential to reduce the reliance on physical resources, thereby contributing to sustainability, the financial implications of adopting such technology cannot be overlooked. The initial costs, coupled with the need for ongoing maintenance and up-dates, pose significant challenges, particularly for institutions and businesses with limited resources. Therefore, a comprehensive analysis of the long-term financial implications is essential to assess the viability of AR in manufacturing training.

5 Conclusions

In conclusion, this paper advocates for the integration of augmented reality (AR) into learning factories as a groundbreaking approach to manufacturing training. The

extended morphology proposed here provides a systematic framework, considering crucial characteristics such as target group, purpose, reality environment, technology, space, assessment, and system integration. The primary purpose of the extended morphology proposed is to provide effective training and guidance in manufacturing programs. The AR technology will be used to create an immersive learning environment, while the learning factory will provide a realistic context for the application of learned skills. By tailoring AR applications to the specific needs of manufacturing training programs, this approach ensures effectiveness, efficiency, and relevance. The efficacy of AR in manufacturing training is evident in its ability to create immersive, interactive learning experiences. However, striking a balance between virtual and real-world elements is crucial to avoid over-reliance on technology and maintain preparedness for tangible challenges in actual manufacturing environments. There is a necessity of balancing technological advancements with pedagogical needs, ensuring that AR serves as a tool to facilitate learning rather than overshadowing fundamental educational objectives. Looking ahead, the prospects of AR in manufacturing education, particularly in combination with technologies like LLMs, offer new avenues for individualized immersive instruction and learning. Ethical considerations, including data privacy and the psychological impact of prolonged exposure to AR environments, are identified as crucial dimensions that must be addressed responsibly. Additionally, sustainability and cost-effectiveness considerations highlight the potential benefits of AR in reducing reliance on physical resources, albeit with the caveat of substantial initial and ongoing costs. In summary, the integration of AR into learning factories for manufacturing training represents a transformative shift in educational paradigms. While challenges persist, the substantial benefits, including enhanced learning experiences, skill acquisition, and knowledge transfer, position AR as a powerful tool for shaping the future of manufacturing education. Ongoing research and development, coupled with a commitment to ethical deployment and comprehensive cost analyses, are essential to realizing the full potential of AR in manufacturing training programs.

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