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# Virtual Reality-Based Training in Additive Manufacturing: Developing a Service Concept that Adapts to Company-Specific Requirements

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**Abstract.** Additive manufacturing (AM), commonly known as 3D printing, has vast amount of technological opportunities, but it also necessitates specialized expertise among its specialists, adopters, users etc. As AM continues to demonstrate its potential and has high growth rates in fields of its use, applications, systems etc., the importance of AM education and training becomes increasingly evident. This paper serves as a preliminary study outlining a novel training concept for industrial AM training including microlearning units and conducted in virtual reality, focusing on the accessibility and flexibility of users. The concept has been developed as part of the ongoing industrial training project. Microlearning and virtual tool-assisted training methods offer effective and agile approaches to enhance the continuous learning of new industrial skills, enabling companies to keep pace with evolving technologies. These tools facilitate extensive customization of training, making company-specific training even more crucial for effective skill development and knowledge transfer. The design of this training concept leverages the user story mapping (USM) method, enabling a deeper understanding of company-specific requirements and needs concerning additive manufacturing training. Moreover, through questionnaires and interviews conducted during the USM process helps identify technology readiness levels (TRLs) of companies in relation to their AM adoption. Measuring TRLs provides valuable insights into the technical maturity of companies regarding additive manufacturing, as readiness levels tend to vary significantly among different organizations. The preliminary framework provided serves as a foundation for designing a modern training concept that cater to the unique requirements of different companies, fostering their successful adoption of AM technologies.

## 1. Introduction

Modern technologies profoundly influence each society, and digitalization impacts daily life. This also includes the interaction of people with one another and extends to the methods they employ for product exploration and procurement. At the forefront of this is the fourth industrial revolution, characterized by a range of innovative technologies; it is predicted to change the manufacturing and distribution of products. Correspondingly, modern, digital manufacturing can now leverage the digital flexibility and efficiency especially offered by additive manufacturing (AM), widely recognized as 3D printing, one of



the most interesting technologies. [1] The rapidly developing field also increases the need for continuous training to keep up with the development of AM. New hardware, terminology, software, and materials are constantly being developed, and information needs to be updated. [2] Despite the abundance of information available on additive manufacturing, it remains crucial to establish dependable research-based knowledge to ensure that learning of the technology is built upon accurate information right from the start avoiding any misconceptions. [3] According to Ernst & Young [4], the need for more experts/professionals for AM is the second most significant obstacle to implementing AM, the first being the high cost of the machines. The reports highlight a considerable need for AM training at the EU level to bridge the gap between AM progress and the knowledge of experts and students. The landscape of AM training in the EU has constantly been evolving in various parts of the EU separately. European standardized regulations are required to tackle this need for more knowledge [5].

Some projects have been developed in the past few years in Europe to provide general guidelines and instruction on addressing the gap between AM knowledge and technology development, such as the European harmonized qualification system CLLAIM [6] and Knowledge Alliance for AM between Industry and universities, ADMIRE [7], to define the qualification required for the whole AM chain, beginning from design to the quality assurance of the finished part. These projects were conducted in collaboration with European Federation for Welding, Joining and Cutting (EFW) to integrate AM qualification system in Europe. [8] In another research [9], a similar review was done internationally by reviewing the recent research in this area, proposing a comprehensive training framework for AM that combines the knowledge from research and education in academia with industrial training to promote the innovative aspects of AM in all aspects to increase its competitiveness. [10]

Digitalisation and time-pressure dynamics in workplaces have revolutionized training and learning approaches. Previously, training was constrained by time and physical location, and the methods employed were not customized to meet the specific needs of individuals. [11] It has been demonstrated that effective learning necessitates individualization and concise learning segments to optimize the learning experience. [12] New avenues have emerged for accessing knowledge, particularly in highly specialized and technology-oriented fields of work. The challenge with SMEs is often that company experts are too busy to join any professional training courses or participate in any presentations, listen to lectures, or even visit YouTube to browse any interesting work-related content. [13] While companies recognize the need for training, resources are often limited for extensive training programs targeting business experts. To overcome this challenge, training can be carried out based on microlearning. This principle allows business experts to focus on their work and, in the event of a problem or need for development, to seek only an answer to a question or development needs in the current situation. [14] Industrial training is characterized by the pervasive presence of technology.

Virtual reality (VR) learning has been discovered to be more effective than using technical manuals or multimedia presentations, especially in complex tasks. This is why new training tools have emerged as the primary instruction means. The sense of physical presence and the inclusion of interactive elements enhance trainee engagement and motivation, contributing to positive learning outcomes. [15] The visual aspect of 360° videos can also make the learning subjects more appealing, especially when combined with effective video thumbnails designed to capture attention and interest. [16] This VR-based training content was specifically designed to facilitate the acquisition of new work-related information by company experts. The content will be accessed through VR goggles provided by the project group. [17]

### *1.1. Background and motivation*

This article emerges from project of the Osuu ja uppoaa, which focuses on designing a virtual reality-based (VR) training concept for industrial additive manufacturing (AM) technology. Osuu ja Uppooa project is funded by European Social Fund (S22515) as a part of COVID-19 pandemic-related actions by the EU. [17] It explores the process and methodology employed to create an effective training experience for AM within an industrial setting. The content curated for the virtual reality-assisted training concept is meticulously selected, drawing upon decades of experience in AM training with diverse target groups. The experts have a rich history of experience and expertise in the field of AM research and training. This paper discusses a pioneering approach to the design of the industrial additive manufacturing (AM) training concept. It combines cutting-edge virtual reality (VR) technology with

one of the latest learning concepts microlearning. The target training group comprises product designers, production managers, middle management supervisors, and individuals responsible for strategic decision-making and investments, specifically within small and medium-sized enterprises (SMEs) in the South-west area of Finland. Although additive manufacturing has been selected as the target technology in this study, the solutions produced are applicable to other technologies.

### *1.2. Methodology*

The method employed in designing the training concept in this study is user story mapping (USM). This approach provides a structured framework for capturing user requirements, prioritizing features, and creating a cohesive roadmap for developing the training concept. Using USM, this study ensures a user-centric design that aligns with the needs and preferences that consider users and their prior experiences with AM. By utilizing USM, the training concept fosters meaningful interactions, tailors content to individual requirements, and incorporates the valuable insights gained from past experiences of users in the AM domain. To be able to ensure that this training effectively addressed the diverse needs and skill levels of different companies, this has to be taken into account in USM tool. Authors have long (c. 15 years) experience of different skill levels of companies in South-West Finland, and also a preliminary questionnaires were carried out before pilot training to understand training needs of companies in AM, and also to understand their skill levels. By utilizing the USM tool to identify company-specific requirements, skill level and training needs in AM, an additional benefit is gained: a deeper understanding of the Technology Readiness Level (TRL) of the companies. [18] The technology readiness level (TRL) measures the maturity of technology for practical implementation [19]. In training, this helps to situate companies based on their maturity to use AM and thus enables them to identify which kind of training can be introduced for the company.

### *1.3. Scopus survey*

A thorough survey was conducted using Scopus, a widely recognized scholarly database to gain a comprehensive understanding of the industrial training landscape. The survey was performed using specific keywords (years 2010-2023) related to the focus of this study. This approach allowed extensive exploration of relevant literature and publications, enabling a comprehensive analysis of the current state of industrial training within the targeted field. The number of published articles in AM training is about 6% of the total published articles in AM in 2022. The trend shows a 75% increase in the number of published articles in AM training since 2018, implying the importance of this topic in the whole spectrum of AM-related subjects. The utilization of virtual reality in AM training also shows an upward trend. The corresponding number of articles in which virtual reality is utilized to improve AM training is 1 % of the total number of AM articles in 2022. However, the number has increased by 80% since 2018. Interestingly, the keywords “user story mapping” and “additive manufacturing” resulted in no publications. Therefore, an examination was conducted on the number of publications containing the keywords "user story mapping" and "training," revealing a noticeable scarcity of studies in this field. Despite the broad applicability of the user story mapping (USM) method in different areas of product design [20], the search on this topic only covered a mere 0.08% of the total available articles on AM. This limited data availability highlights the need for further research. It leads to the conclusion that the case of this study holds significant relevance, as there is limited or negligible availability of publications addressing the subject matter discussed in this article.

## **2. Description of digital training tool approach**

Microlearning is an effective training approach for organizational learning. Subject matter experts are crucial in microlearning, providing accurate narration and demonstrations. [21] Some industrial training institutions combine traditional exercises with microlearning tools, enabling focused assignments and reinforcing understanding. [13] Microlearning values active problem-solving as an immediate application of knowledge, and prompt feedback contributes to efficient information absorption. However, it may only be suitable for some skills. Numerous case studies consistently demonstrate the efficacy of microlearning in improving learning outcomes, as e.g. in [22]. Comparisons with control groups using traditional methods reveal higher test scores, self-reported competence, and learner

satisfaction among microlearning participants. Retention assessments prove that microlearning groups outperform control groups in long-term knowledge recall. Nevertheless, microlearning has some limitations. These include the potential for information overload, distractions from device features, internet connectivity issues, affordability of hardware, and limited access to immediate teacher guidance, particularly in remote learning scenarios. [23]

Virtual reality has been employed as a training tool in various fields. It allows users to examine and interact with training subjects closely. For instance, virtual simulations can assist in motor skill development, such as practicing basketball throws. [24] The VR-based simulation will also improve operational efficiency when creating a safe, reliable, realistic educational environment. Similarly, VR can be utilized for training in operating and maintaining complex machinery, allowing users to virtually explore the equipment, interact with its components, and receive detailed instructions. [25] This shortens the learning time, lowers any risk perception, and allows training not to affect production without decreasing user and machinery safety. [26] The VR experience can even work better than a real-world experience based on the security of this experience and its costs. [27] 360° videos have been explored as an affordable alternative to accurate virtual reality solutions in industrial training.

While VR requires complex 3D modeling and software development, 360° videos offer a more straightforward approach. [28] They can be filmed and played back using basic systems without extensive customization. The user can choose the target he/she wants to view, and he/she does not have to settle for the selection of video makers. [29] Some proprietary 360° video solutions even allow for the addition of interactive elements, such as displaying icons that trigger playback of related sub-topic videos. [30] The user can choose the target he/she wants to view, and he/she does not have to settle for the selection of video makers. [29] This combination of 360° videos and interactive features aligns well with microlearning principles. This is precisely why these two elements are integrated into the AM training concept. Use of microlearning in virtual learning training aligns well with the characteristics of digital natives and the modern learner. These individuals often prefer quick, on-demand access to information and have shorter attention spans. Microlearning meets their learning preferences by offering concise, interactive, and engaging modules that cater to their learning needs. The microlearning approach in virtual learning training also offers a learner-centred and efficient way to deliver knowledge and optimize the effectiveness of training programs.

### **3. Virtual reality-based training for small and medium-sized companies**

The most challenging aspect of making digital capability visible lies in providing a purposeful description of the work system, of which digital capabilities are an integral part [31]. The technical expertise of the training concept plays a mediating role, aiming to enhance the understanding of experts in their operating environment, thereby improving the successful implementation of desired development steps, agile experiments, and more profound changes. Consequently, the new training concept and knowledge transfer approach encompasses the skills and means necessary for comprehending and advancing the contents and processes of business, process, and work digitalization. When describing the training concept, it was found helpful to incorporate a third interpretation in the training concept representation in addition to the technical-economic and socio-political interpretations. This third interpretation emphasizes key concepts of trust, social capital, and collaboration [50,51]. The social nature of capabilities within complex situations and subjects is a significant factor that should be highlighted in the design of technical content (e.g., fundamentals of AM) and technical implementation (e.g., distance and micro-learning). Otherwise, attempts to enhance capabilities may remain superficial or get lost in the information overflow if the personal and social dimensions are not considered. In this sense, this is also a matter of management and HR issues in every participating organization. [35,36]

Contents of VR training material have been created based on the understanding of the skills of AM experts and knowledge needed for proper AM work and based on questionnaires identifying the needs of company experts for AM-related information. Based on these requirements, theoretical and practical content is included, all in a virtual reality environment. An entire AM theory introduction course is included for the theory part but is divided into presentations lasting only 5-10 minutes according to the microlearning principles. The practical part consists of presentations of providers of AM products and services and also presentations of a few companies who are keen to understand more about the

possibilities of AM production. Brief company introductions are included for all participating companies as well as contact details of university experts, the training concept, and a reference to the participating individuals. [37]

#### 4. Developing training product

##### 4.1 User story mapping as a tool for concept design

In the traditional approach to training concept development, designers rely on their ideas and assumptions about how the product or service will be used. However, the actual value of the final product can only be realized if end-users are included in the design phase. One of the main challenges in this process is determining the most effective method for documenting, describing, and transferring the knowledge gathered from users, particularly in the context of services. [38] This challenge becomes even more critical in the case of services related to learning, where user feedback and dialogue are crucial components of the design training process. While primarily introduced and employed in software development, the user story mapping (USM) has become a versatile approach for organizing and disseminating information about a product or service [38]. As previously mentioned, adopting a learner-centric approach is a crucial element for an effective deep-learning process. To accommodate learners with diverse knowledge backgrounds, the USM method has been selected as the foundation for designing this virtual reality-based training concept, especially when dealing with new technologies such as AM. This technique plays a pivotal role in comprehending user needs and experiences and ultimately in devising practical solutions to real-world problems [20]. In the AM training, using the USM method in designing a training concept emphasizes dialogue with Users and time efficiency, which are critical elements in an industrial context.

User story mapping (USM) for domain modeling is a method derived from the software functionality definition domain, which puts the end-user and his perspective in focus. [20] The domain of interest is defined through the collection of user activities, which indirectly gathers all actors, resources, processes, and overall dynamics. [38] The original USM method is divided into two key dimensions (see Figure 1): 1. User and 2. Usage. In this study, the term "user" encompasses a diverse group, including experts such as product designers, production managers, middle management supervisors, and individuals responsible for strategic decision-making and investments within SMEs. Engineering students and other stakeholders who actively participated in piloting the training concept are also considered users in this context. The "Usage" dimension in Figure 1 includes standardized Steps, while the user can select the specific Activities within these Steps. This allows flexibility and personalization, as the training can be adjusted to address specific skill levels, learning styles, and objectives of each user. [20] chosen by users form the backbone of the training concept. In this virtual-based AM training context, four User Steps are identified. The first is Pilot training in Figure 1, that provides a concise overview of the AM theme. It serves as an introduction to familiarize users with the fundamental concepts and principles of additive manufacturing. In the second step, preparation for training, Users receive guidance on effectively using the virtual reality goggles and navigating between different training content. The focus is ensuring users are comfortable with the technology and can access the training materials seamlessly. In the third, Training step, users engage in the core training activities by selecting relevant learning content that supports their specific individual and organizational needs and objectives. The training materials cover various aspects of AM, such as design principles and manufacturing processes. The last step, Evaluation in Figure 1, assesses what is learned and how that can be implemented in a real-life work context. The user experiences obtained from various Activities consist of User Stories. [20] These user stories encapsulate valuable data that guides the development and individualization of the training concept, ensuring that it aligns closely with the needs and preferences of the users. These User stories build the backbone of the USM model.

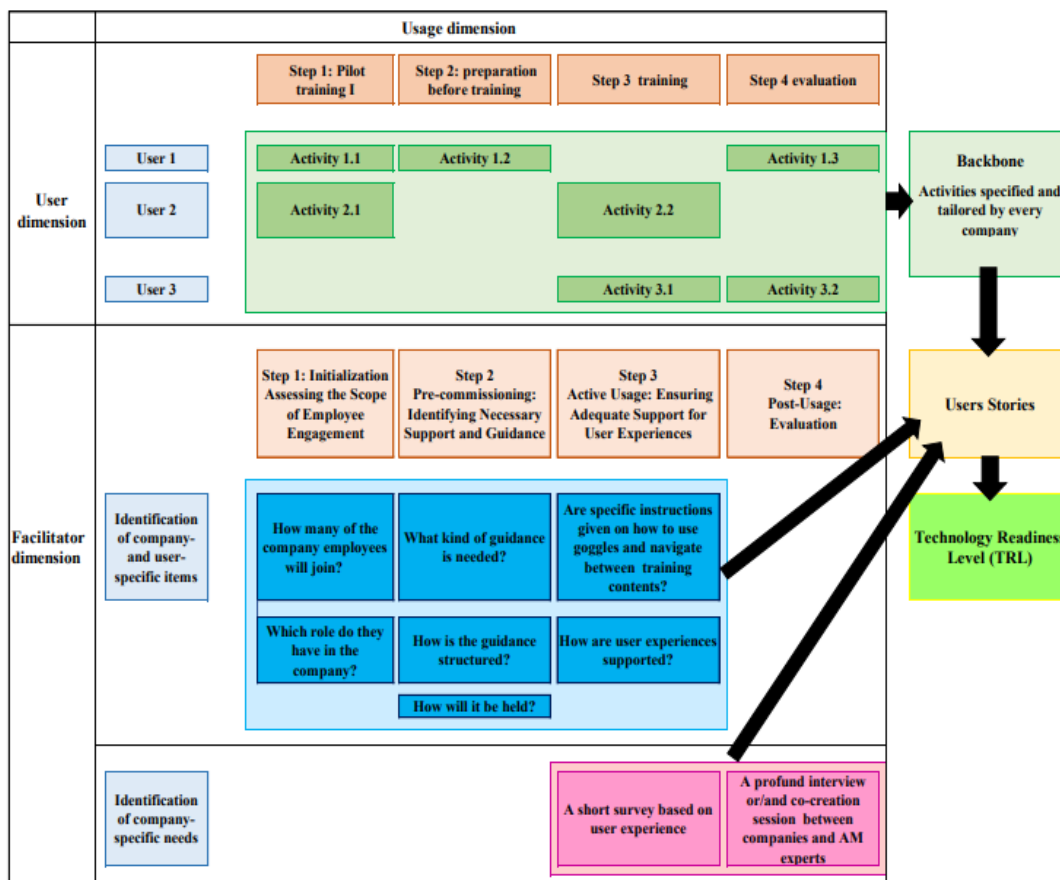


Figure 1. User story mapping (USM) modified from Kiritsis et al.[20]

The USM (user story mapping) model (Figure 1) has been modified to meet the requirements of the Virtual Reality-based Additive Manufacturing training concept. Because of the nature of training design, a new dimension called "Facilitator" has been introduced. In the literature, facilitator has various roles and activities. [39] According to Stetler et al. [40] facilitator is defined as a person who has a supportive and problem-solving function. According to Kolb et al. [39], the facilitation process involves skilfully managing interaction to create a positive and productive experience, where the facilitator plays a crucial role in actively encouraging interaction among participants to achieve the goals effectively (in this case, learning goals). Through this dimension, users gain valuable support relating to technical and educational issues in virtual reality-based AM training. By incorporating the Facilitator dimension (as shown in Figure 1), the model enables to design a more tailored and relevant learning experiences with learning supportive dialogue, aligning with the unique needs of each organization and individual. In this particular model, the utilization of user stories contributes to a comprehensive understanding of various aspects of the training process, enabling the design of a unique and customized training concept. Furthermore, user stories serve as an additional output by providing insights into the Technology Readiness Level (TRL) of the companies involved.

#### 4.2 Technology readiness level

The technology readiness level (TRL) measures the maturity and readiness of the technology for practical implementation, progressing from early stages to deployment on a scale of 1 to 9. NASA initially developed TRL as they needed to evaluate the maturity level of different new technologies. [41] TRLs are used, for example, in aerospace, to assess technology readiness, guide decision-making, and funding, and facilitate integration into real-world applications. [42] TRLs, ranging from 1 to 9, were

developed by NASA to assess technology maturity. [43] Lower TRLs (1-3) represent the conceptual phase, while higher TRLs (4-6) involve validation and prototyping. TRLs 7-9 indicate full maturity and commercial availability, as in [44]. The TRLs help assess the technology readiness of companies for adopting AM by evaluating their maturity and preparedness. Aligning these readiness levels ensures effective training that meets specific company needs and enables customization through virtual reality-based tools. This systematic approach serves as a reference for decision-making, resource allocation, and continuous improvement in training technology. Factors such as adaptability, openness to new technologies, and willingness to embrace change impact the successful implementation of training technologies. Additionally, the characteristics of the technology itself, including user-friendliness, reliability, and scalability, play a crucial role in determining its readiness for integration into training practices. Recognizing the AM traits allows for a comprehensive evaluation of technology readiness (as in [44] and [45]), facilitating the selection of suitable AM technologies and maximizing their effectiveness in supporting learning and development. [46] and [44] introduce Education Readiness Levels (ERL), which aim to assess the "readiness" of the training module. Ten readiness levels have been defined for each element, based on the Technology Readiness Level (TRL) definitions. Authors will study this topic in the future more closely to be able to construct Training Readiness Level for training purposes.

During the development of the training concept, a significant challenge arose with SMEs: these organizations often operate under constraints that limit the time available for dedicated training or information gathering. Their resources are primarily allocated toward daily work activities and routines. Investing in new machinery or developing new work processes on modern technologies is a big challenge among SMEs because they have invested in their current machinery, and the investments must be worth the money. Considering the ongoing challenges of companies due to post-pandemic time and the complex global logistics and wartime conditions in Europe, small and medium-sized enterprises (SMEs) find themselves compelled to adopt short-term planning strategies and avoid long-term investments, particularly in emerging technologies like additive manufacturing (AM). The limited availability and realistic understanding of AM within their specific fields make it difficult for SMEs to envision its implementation and justify long-term commitments. Recognizing the limitations and challenges faced by SMEs in terms of work environment efficiency, it becomes even more crucial to meticulously customize company-specific training opportunities. User story mapping is a valuable tool for this kind of concept design, as it allows designers to gather user feedback and dialogue, leading to practical solutions. The method focuses on user activities and usage, providing flexibility and personalization. User stories form the backbone of the training concept in this study, guiding its development. The user story mapping model has been modified for virtual reality-based training, introducing the "Facilitator" dimension to provide technical and educational support. Technology readiness level (TRL) measures the maturity of technology for practical implementation. Aligning training technologies with appropriate TRLs ensures testing, validation, and pedagogical suitability.

The study recognizes AM as an emerging manufacturing technology with rapid growth. As a result, the demand for industrial AM training is escalating. The findings underline the significance of developing comprehensive training frameworks encompassing various types of training to cover the diverse needs of different companies. Furthermore, utilizing new, virtual reality-based tools provides opportunities for extensive customization, enhancing the effectiveness and efficiency of training programs. This study concludes by presenting a preliminary framework for creating company-specific training programs in additive manufacturing.

This framework serves as a foundation for designing effective training concept that accommodates the specific requirements of companies with different background knowledge. By establishing a structured approach to training development, organizations can maximize the benefits derived from AM technologies and accelerate their adoption and integration into their operations. In addition to the technology readiness level (TRL), Education Readiness Levels (ERL) have been introduced to assess the "readiness" of training modules in AM training. [44] ERLs align with TRL definitions and define ten readiness levels for each element. [46] This approach allows for a comprehensive evaluation of technology readiness, enabling the selection of suitable technologies for effective learning and development. Further research will aim to construct Training Readiness Levels for training purposes.

Evaluating maturity, adaptability, and technology characteristics ensures effective training and supports the successful integration of AM practices.

## 5. Conclusions

The rapidly evolving field of AM requires continuous training to keep up e.g. with hardware, software, and material advancements. Establishing research-based knowledge is crucial to avoid misconceptions. Training, especially industrial training, is essential at all levels of the organization to support product development and enhance expertise. This study investigates the feasibility of virtual reality (VR) based on industrial training in additive manufacturing. The aim is to develop an effective training concept for small and medium-sized enterprises (SMEs) in the AM industry. The study utilizes microlearning methods and 360° video materials to create an engaging and tailored training experience. User story mapping (USM) is employed to understand the specific training needs of companies in the AM field and ensure that the training program aligns with their requirements. The study also assesses the technology readiness levels (TRLs) of companies regarding the adoption of AM. The research findings contribute to the development of a VR-based training concept for AM, considering the unique challenges and requirements of SMEs.

Combining these approaches tailored by the user story mapping method can revolutionize industrial AM training, and offer personalized, immersive, and efficient learning experiences. By leveraging modern technologies and methodologies, companies can enhance their competitiveness and bridge the gap between AM progress and expert knowledge. As the field of AM continues to grow, the importance of such training approaches will expand, ensuring that professionals are equipped with the necessary skills and knowledge to leverage the potential of this innovative technology. Topics for further studies were found in exploring the effectiveness of virtual reality-based industrial training in AM, in enhancing user engagement and interaction in virtual reality-based AM training, optimizing user story mapping for tailored additive manufacturing training, and assessing the readiness levels of companies for adopting additive manufacturing.

During the preparation of this work, the authors used Chat GPT and Grammarly in order to reformulate and improve the structures of sentences and as a tool to find synonyms and different expressions to avoid tautology. After using these AI tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Piili and Huusko drafted the idea of this publication. Further brainstorming was executed by all authors. The actual drafting of the concept of education approach introduced in this article was discussed, commented on, and modified by all the authors. Susi drafted the first approach to VR/360 training concept and practices for it, and this was used as part of this article. Huusko, Piili, Tuomisto, Helin, and Parchegani carried out a theoretical review and editing of it. Huusko developed a USM method draft for this article, and it was discussed and modified by all authors. Salminen reviewed, supervised, provided Resources and Funding acquisition. The final draft of the publication was discussed, commented on, edited, and modified by all authors.

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and training concept that has been essential for carrying out this study. Authors would like to thank also to staff of Turku School of Economics and Department of Mechanical Engineering in Faculty of Technology at University of Turku for their knowledge and help to be able to execute this study.

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