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Extended Reality (XR) and Hands-on Training Methods Comparison Report

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Contents

1. Foreword

The AREOLA project is a part of the Erasmus+ program and involves a consortium of organizations, namely EOS, EWF, FA, IDONIAL, LAK, MakeReal, and MTC, listed alphabetically. One of the project's purposes is to develop educational materials that leverage digital technologies to enhance vocational training in the field of additive manufacturing.

The emergence of the Covid-19 pandemic has stimulated online education and the integration of various digital technologies into education. This has increased the importance of more innovative education methods in place of traditional education methods. As technological advancements continue to reshape the landscape of education and training, various methods have emerged to enhance the learning experience. In response to this transformation and to make vocational education and training more appealing and aligned with the modern era, the AREOLA project has dedicated itself to developing digital educational content. However, the project goes beyond just producing digital content; it also investigates the pedagogical implications of employing these technologies.

To achieve this, the project developed materials for theoretical training for online deployment and extended reality materials for practical training. These materials also tested by means of pilots in the Project Result 4.

In this report pilot studies results that involved a comparative analysis between on-site practical training and learning through the use of Extended Reality (XR) tools are presented. The focus was on how these approaches impact learners and contribute to the accomplishment of educational outcomes. This report aims to compare two distinct teaching methods: Virtual Reality (VR)/Augmented Reality (AR) also called in this report as Extended Reality (XR), and hands-on (traditional). Each method has unique advantages and limitations that impact their effectiveness in delivering educational content and skill development. The findings within this study will contribute to our understanding of how XR tools impact vocational education and particularly PBF-LB operator training in the Aerospace sector. This report is intended for a diverse audience, including VET (Vocational Education and Training) providers, VET trainers, researchers in the field of educational technology, as well as trainers and training developers in the Aerospace sector and other industries that utilize additive manufacturing technology.

2. Hands-on (Traditional) Method for Practical Learning

Training employees hold significant importance for virtually all businesses, whether they are bringing in new hires or upskilling their existing workforce to enhance overall operational efficiency. This holds especially true for industries that deal with highly complex processes and carry significant risks. Practical, hands-on training is an integral component of these programs, allowing employees to gain valuable experience in real-world scenarios [9]. However, it comes with its own set of limitations. Firstly, practical training can be resource-intensive, requiring substantial financial investment in equipment, facilities, and skilled trainers. This financial commitment can strain a company's budget, making it essential to seek cost-effective alternatives.

Furthermore, the risk factor associated with practical training cannot be underestimated. In industries with high-risk operations, conducting hands-on training can expose employees to potentially dangerous situations. This necessitates the implementation of stringent safety protocols and measures to mitigate these risks, adding an extra layer of complexity and cost to the training process. Moreover, practical training may fall short in fully conveying the intricate internal structure and operational processes of complex machinery and systems.

Logistical support also presents a challenge in practical training. Coordinating the availability of equipment, facilities, and trainers with the schedules of the employees can be a logistical puzzle, often requiring meticulous planning and coordination. Delays or hiccups in this process can disrupt the training schedule and affect productivity.

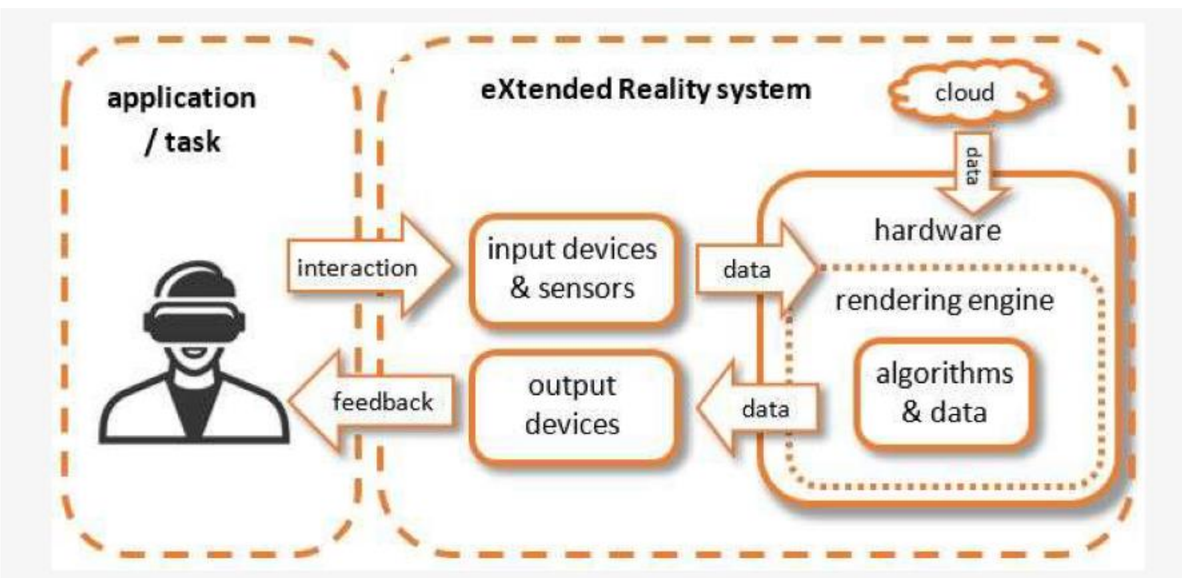
In such domains, the need for cost-effective training programs becomes imperative as they serve the dual purpose of reducing training-related risks and enhancing training outcomes while also curbing training costs. To address these needs contemporary technologies can be offered as an alternative solution, XR might be considered to meet the training requirements

3. Using Extended Reality in Training / Education Settings

Extended Reality (XR) is a term that covers different technologies that alter reality by adding digital elements to the physical or real-world environment. Some examples of XR are Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). XR can be used for various purposes, such as entertainment, military, healthcare education, and industry training for manufacturing. XR can create immersive and engaging experiences where users can interact with computer-generated elements in real-time [1]. These technologies, when used with specialized headsets, glasses or displays, can insert virtual and digital 3D elements into users' surroundings using holograms.

The utilization of XR systems is expanding across various sectors today, including social media, healthcare, entertainment, tourism, and education. XR technology's ability to simulate different environments is increasingly being used in education. It is emerging as one of the most widely used methods for training as it makes high-risk training less risky through simulation, reduces the costs associated with logistically demanding training programs using virtual environments, and increases understanding of abstract concepts through simulated experiences [2].

Another motivating reason for the adoption of XR systems in education is the enhanced level of interaction they offer. Thanks to haptic gloves and wearable sensors, XR systems enable users to experience a sense of touch and other sensations. This capability effectively bridges the divide between the real world and the virtual environment. The picture below explains the major components of an XR system and shows the interaction between user and devices.



Picture 1. The XR system workflow [12]

3.1 Using the XR in Additive Manufacturing Training

Additive Manufacturing (AM), commonly known as 3D printing, has revolutionized the way to create objects and products. From aerospace to healthcare, this technology has found applications in various industries. However, harnessing the full potential of additive manufacturing requires a skilled workforce. To achieve this, training plays a crucial role. One innovative approach to enhance the effectiveness of AM training is by incorporating Extended Reality (XR) technologies which combines Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) to provide immersive, interactive, and engaging training experiences [10].

XR systems are preferred in AM training as these technologies allow us to create immersive learning environments, design realistic simulations, provide interactive training, easily customize and adaptable and finally enable remote training and collaboration. Furthermore, it bridges the gap between theory and practice, offering a risk-free environment for trainees to develop their AM skills. As the technology continues to advance, XR's role in AM training is only set to grow. It enables AM education more accessible, cost-effective, and adaptable to the evolving needs of industries. By incorporating XR, the additive manufacturing sector can ensure a well-trained workforce capable of harnessing the full potential of this revolutionary technology [7]

3.1.1 The benefits of using XR tools in Additive Manufacturing Training

XR technology is already being used for employee training and development in various industries, including aerospace and manufacturing. Here are some benefits of using XR technologies in additive manufacturing training:

1- Simulating real working environments: XR technologies create virtual environments that replicate real-world experiences, enabling companies to enhance their employees' skills through simulated training. This allows individuals to practice tasks such as piloting, including takeoffs and landings, in a virtual setting before embarking on actual real-world experiences [3].

2- Creating safe environments: XR technologies offer a safe learning environment where trainees can learn from their training errors, minimizing potential risks. For instance, technicians can practice high-voltage switch operations without any real-world danger involved [3].

3- Saving money: XR technologies cut down training expenses by reducing the costs associated with training equipment and physical environments. As an illustration, training employees in aircraft engine repair through virtual reality is more cost-effective than utilizing actual aircraft equipment for the same purpose [3].

4- Helping learners stay focused: XR maintains the trainees' concentration on their training by isolating them from real-world distractions. This results in an extended attention span, enabling quicker absorption and acquisition of new knowledge [5].

5- Reducing plant downtime: XR allows companies to continue their production activities without interruptions, preventing disruptions in their earnings resulting from training activities. [6]

6- Real-time guidance: XR technology offers immediate feedback to employees on the production floor, saving time by eliminating the need to revisit training resources or constantly seek guidance from supervisors. This real-time assistance greatly reduces time spent addressing challenges on the production line.

3.1.2 The limitations of using XR tools in Additive Manufacturing Training

While XR tools offer numerous advantages for Additive Manufacturing (AM) training, there are some disadvantages and challenges associated with their use. It's important to be aware of these potential drawbacks:

1- Expense: The development and deployment of XR tools in a 3D environment, along with the ongoing maintenance and software updates, can be cost-prohibitive [3]. Moreover, the high cost of hardware further restricts access to these technologies, making them inaccessible to a broader audience [8].
2- Technical difficulties: XR technology is relatively new and therefore the implementation process may face technical difficulties. These issues can lead to delays in training and potentially reduce the overall effectiveness of the training program [7].
3- Absence of Personal Interaction: XR training, although immersive, lacks the personal interaction that traditional training methods provide. This can be a disadvantage for trainees who value face-to-face interaction with trainers and colleagues [3].
4- Motion Sickness: XR technology use can induce motion sickness in certain trainees, potentially compromising the overall effectiveness of the training program [7].
5- Lack of Adaptability: XR-based training often lacks the flexibility of traditional training, where employees can actively contribute suggestions and raise questions. XR programs

can be less adaptable to individual requests, limiting trainees' learning opportunities, as they are constrained by predefined software.

4. Method

According to the objectives of this project result, AREOLA project partners organized practical training to integrate the XR tools in training environment and to compare the XR and hands-on method. The XR tools employed in this work were developed in the context of AREOLA project.

4.1 Use Cases

To identify suitable Additive Manufacturing use cases for the development of XR tools, an in-depth review of the practical operations integral to the PBF-LB qualification was conducted. The selection process involved evaluating the ten most promising use cases using a comprehensive matrix that considered industry demand, compatibility with XR training tools, and the overall value for Vocational Education and Training (VET) centres and students.

The matrix comprised distinct criteria categorized to effectively assess each potential use case outlined in the EWF guideline for "International Metal AM Operators: Powder Bed Fusion – Laser Beam." These criteria included:

- **Knock-out Criteria:** Essential conditions for successful transformation of analog content into XR, emphasizing factors like the availability and accessibility of accurate 3D/CAD data.
- **Use Case Classification:** Considering XR's capacity for 3D animations, this category evaluated the practicality of implementing XR content for practical applications or training with a focus on manual steps versus theoretical content.
- **Business Case:** Beyond technical feasibility, this criterion examined the business aspects and impacts associated with each use case.
- **Risk Assessment:** Assessing the potential to safely depict potentially hazardous content in XR training, safeguarding both trainees and equipment.

- **XR Related:** Drawing on experiential factors, this category considered aspects less reliant on hard facts, similar to the "Business Case" section.

The down-selection process also involved a thorough examination of how these practical operations are currently taught, including the training materials associated with each Competence Unit (CU) within the PBF-LB operator qualification related to Competence Unit 21: Maintenance of PBF-LB systems under the International Additive Manufacturing Qualification System (IAMQS).

Following the down-selection of practical scenarios, the available XR tools were assessed, with Unity 3D being chosen as the software tool for developing practical use cases in Virtual Reality (VR). Unity 3D was selected for its widespread use in immersive application development, offering capabilities for both local development and deployment, essential to meet the stringent data security requirements in the Aerospace sector.

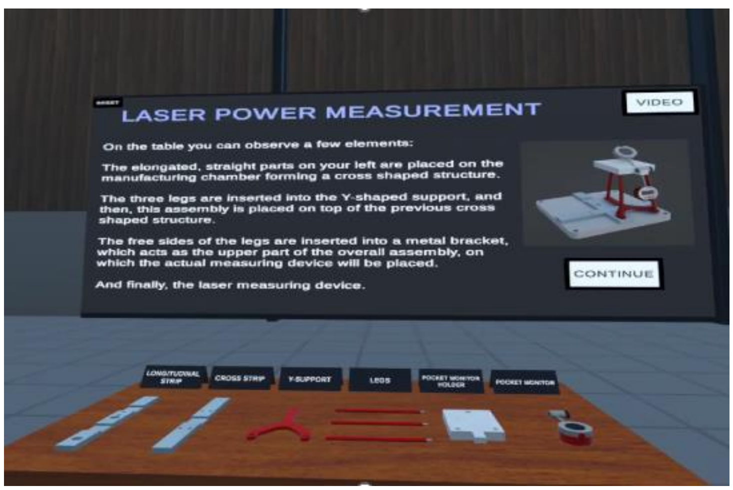
One of the identified use cases for the piloting phase involves the development and deployment of an XR application for the recoater blade replacement and alignment scenario. This particular scenario concentrates on the precise alignment of a recoater blade, encompassing the positioning of a recoater blade housing and the procedural steps for aligning recoater blades, as illustrated in Picture 2.

Picture 2: Recoater blade use case

Another use case selected for development in the piloting phase is the *Health and Safety Walkaround* scenario. This particular use case aims to familiarize users with personal protective equipment, impart understanding of machine-specific safety mechanisms, and provide knowledge regarding safety-critical areas of the machine. The scene for the Health and Safety Walkaround use case is depicted in Picture 3.

Picture 3: Health and safety walkaround use case

The Laser Power Measurement scenario has also been developed into the XR application. This use case is centered around verifying the laser power, a crucial procedure for additive manufacturing job. Given that the laser system plays a pivotal role in generating the energy required for fusing particulate material, operators must ensure its optimal functioning to prevent any degradation or alterations. A scene from the Laser Power Measurement scenario is depicted in Picture 4.



Picture 4: Laser power measurement use case

4.2 Design of the Pilot Course

The study is structured as an experimental study within the context of the AREOLA project. Pilot studies were executed across multiple locations, including Portugal, Spain, Germany, and the UK. Specifically, IDONIAL, EOS, and MTC conducted these pilot trainings within their respective facilities. Notably, FA collaborated with another organization in Portugal, namely ISQ, and together, they executed the practical piloting at ISQ's facility. It's worth noting that certain partners scheduled training sessions extending beyond a single day, indicating the comprehensive nature of the training activities conducted as part of the study. In addition, RWTH Aachen University, an associate partner in the project, conducted a pilot session.

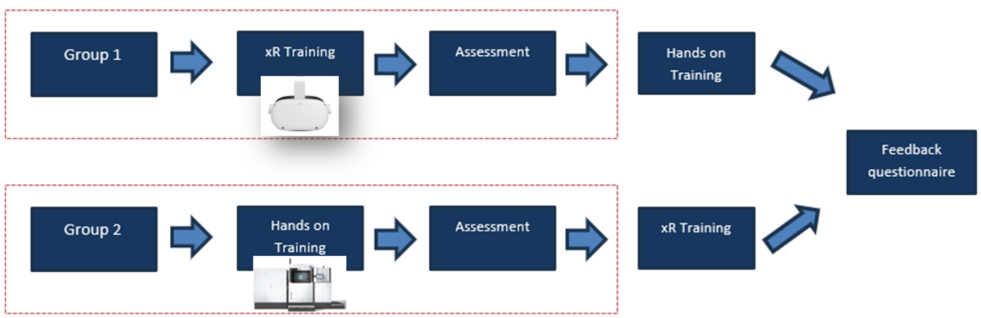
Partners selected one use case based on their available PBF-LB machine model, but all partners adhered to the same design for collecting data to facilitate the comparison of the two methodologies employed in the AREOLA project. The details of the pilots done by partners are given below in Table 1.

Table 1: Partners’ practical pilot session details

Country	Partner	Nº Trainee	Use-cases	Date
Germany	EOS	6	Laser power measurement	19-20th September
		2		14th November 2023
Portugal	FAN	12	Health and Safety Walkaround	13th November 2023
Spain	IDONIAL	11	Laser power measurement	8th November 2023
		8		14th November 2023
UK	MTC	5	Recoater blade	26th September
		5		18th October
		7		25th October
Germany	DAP RWTH (Aachen University)	4	Health and Safety Walkaround	17th of January

Training participants were divided into two groups: one group underwent hands-on training, while the other engaged in XR method sessions. Both groups were instructed on the same content in both methodologies. Upon completing their respective training sessions, each participant tackled assessment questions designed to capture trainee knowledge retention. Then, the groups switched methodologies, providing each group with the opportunity to experience both approaches. At the conclusion of the training, trainees and trainers filled out a feedback questionnaire specifically designed for them to express their sentiments regarding the utilization of these two different methodologies. The design schema of the pilot session is outlined below.

Figure 1: The design skim of the practical pilot followed by all partners



After finalizing the practical piloting, partners conducted national virtual roundtables to validate the pilot results, gain insights about the trainees' takeaways, and assess the future impact of the AREOLA project on the PBF-LB operators' training.

4.3 Instruments

The assessment questions have been developed by the project partners to cover the learning outcomes of the training content. As mentioned earlier, the same content has been taught to participants in both the hands-on training and XR method. There are three different assessment sets associated with the training content: the health and safety walkaround training scenario has three multiple-choice questions, and the laser power measurement and recoated blade change scenarios have four assessment questions.

To collect participants' feedback related to their experience with the used training methods, a feedback questionnaire was developed. There are eight questions in a 4-point Likert scale, including aspects such as pedagogy, interactivity, encouragement to learning, and so on. Some sample questions are: “This method was interactive,” “This method made the content easy to understand,” and “I enjoyed this training method.”

Additionally, a feedback questionnaire (see appendix I) was developed by partners for trainers to express their opinions on two different training methods. After completing the entire training session, the trainers provided responses to the feedback questionnaire. The questionnaire comprises three sections: the first section gathers trainers' information, the second section is designed to assess practical learning methods (4 questions, each using a 4-point Likert scale), and the third section consists of open-ended questions that enable trainers to delve deeply into their opinions regarding the advantages, limitations, and opportunities for improvement.

The feedback collection of the virtual roundtables was conducted using semi-structured discussion questions, and partners had the flexibility to introduce additional or different questions during the flow of the discussion. Examples of such questions include: "How would the course (both theoretical and the pilot course delivered as part of the AREOLA project) contribute to your Additive Manufacturing (AM) future?" and "What are your thoughts on the potential impact of the AREOLA project on the training of PBF-LB operators?".

4.4 Participants

Eight practical pilot sessions had been conducted to gather the required data to compare these two methodologies and to come up with the result of the percentage of practical training that could be delivered by XR tools method.

A total of 61 participants attended the practical pilot training. Most of the participants (50.9%) fall within the 26-40 years old interval, while 20% are in the 41-57 years old interval. Additionally, 18.2% are in the 19-25 years old interval, 3.6% are in the 16-18 years old interval, and finally, 1.8% are in the 58+ age group.

49.2% of the participants are engineers, 5.1% are operators, 22% are technicians, 3.4% are designers, and 20.3% have chosen other options, specifying themselves as students and PhD students. In terms of educational levels, 44.1% have an undergraduate degree, 18.6% graduated from high school, 23.7% graduated from technical and vocational schools. Additionally, 11.9% hold graduate degrees.

Among the participants, 43.6% had no prior experience with XR technologies, 30.9% had used the technology before for general purposes, and 16.4% had utilized XR tools for other training purposes.

Additionally, 66 participants joined the virtual national roundtables, with some having already attended AREOLA project pilot trainings (both theoretical and practical), while others were first time hearing about the AREOLA project. The virtual roundtable participants were from the manufacturing sector, mainly working as engineers, designers, trainers/teachers from vocational schools, training providers and higher education institutions, as well as university students from related disciplines (mechanical engineering and materials engineering).

4.5 Data Analysis

The pilots' data was collected through assessment and feedback questionnaires. This gathered data has been analyzed via SPSS V22. First of all, a descriptive analysis was conducted to define the sample characteristics and also check if the data distributed normally or not. As the skewness and kurtosis values were found to be between +3 and -3, the data distribution is accepted as normally distributed. To compare the mean scores between the hands-on and XR methods on the success and satisfaction, t-tests were conducted. Furthermore, ANOVA was used to understand the relationship between age, previous use, and preference for XR tools. Additionally, content analysis has been done to analyze the open-ended questions in the feedback questionnaires and the data collected through the virtual roundtables.

5. Findings

5.1 Success score between hands-on and XR methods

An independent samples t-test was conducted to compare the mean scores between the hands-on group (M =74.14, SD = 19.95) and the XR group (M= 65.24, SD=30.82). The t-test revealed no statistically significant difference in scores between the two groups, $t(60)$= 1.32, p= 0.19. (See Table 2)

Table 2. Independent sample t-test results

	Method	N	Mean	Std. Deviation	Std. Error Mean	t
Score	Hands-on	28	74.14	19.95	3.77	1.32
	XR	34	65.24	30.82	5.28	

The results indicate that there is no statistically significant difference between training with hands-on and XR methods in terms of achieving learning outcomes.

5.2 The Feedback Score Differences between Hands-on and XR method

To analyze the differences between hands-on and XR methods, a paired-sample t-test has been conducted. The test method has been selected as we have collected paired data, meaning each participant experienced both the hands-on and XR methods. Based on the analysis result of the paired-samples t-test (as given in the Table 3), there is not a statistically significant difference between the hands on (M = 26.38, SD = 7.12) and XR methods (M= 26.75, SD= 3.35), t(52) = 0.72, p >.005 (two-tailed). The mean difference between Hands-on and XR method score was found to be -0.38, the 95% confidence interval for the difference ranged from -2.51 to 1.75.

Table 3. Paired sample t-test results

Variable	*Hands-on*	*XR*
Mean (M)	26.38	26.75
Standard Deviation (SD)	7.12	3.35
t-Statistic	-.355	
Degrees of Freedom (df)	52	
p-Value	0.724	
95% CI for Mean Difference	[-2.5101, 1.75]	

The results indicate that there is no significant difference in user experiences between Hands on and XR methods.

5.3 The differences between XR feedback score and age

To investigate differences in XR scores across five age groups (Group 1: 16-18 years old; Group 2: 19-25 years old; Group 3: 26-40 years old; Group 4:41-57 and Group5: 58+), a one-way ANOVA was conducted, the results are given in Table 4. The ANOVA results yielded an $F(4,47)=1.16$, p-value=0.34. Therefore, there is no significant difference in XR scores across the five age groups.

Table 4. The ANOVA results show differences in XR tools feedback scores based on age

Source of Variation	Sum of Squares	Degrees of Freedom (df)	Mean Square	F-Statistic	p-Value
Between Groups	58.43	4	14.61	1.16	0.34
Within Groups	591.80	47	12.59		
Total	650.23	51			

The analysis suggests that age doesn't seem to play a significant role in individuals favoring the use of XR technology.

5.4 The differences between XR feedback score and previous usage of XR

To investigate the differences between previous usage of XR tools across the three groups of previous experience (Group 1: Yes, in other training; Group 2: Yes, but only in general way; Group 3: No and the favoring the XR tools, one way ANOVA test was employed. as shown in Table 5.. The ANOVA results yielded an $F(2,50)=0.07$, p-value=0.94. Based on the results, there is no significant difference in mean XR scores across the three groups of previous experience.

Table 5. The ANOVA results show differences in XR tools feedback scores based on previous usage of XR tools

Source of Variation	Sum of Squares	Degrees of Freedom (df)	Mean Square	F-Statistic	p-Value
Between Groups	1.71	2	.86	.07	.94
Within Groups	650.1	50	13		
Total	651.81	52			

These findings suggest that there is no statistically significant difference in XR scores between the user's previous experience. In conclusion, familiarity with XR technology is not a determining factor for favoring XR tools for training based on the ANOVA result.

5.5 Participants thoughts on the used training methods

The participants also wrote their thoughts about the advantages and limited aspects of both methods. Their responses have been summarized and categorized based on the common answers below.

5.5.1 Advantages of Hands-on training method

Participants stated their opinions about the most liked part of the hands-on training method. Most participants agreed that hands-on training offers opportunities for trainees. For example, it provides trainer-trainee interaction, proximity to real equipment, and allows trainees to receive immediate feedback from trainers. Here are some quotations from participants:

- You can ask teacher questions. (PT12)
- Real hands-on experience, realistic conditions, immediate feedback. (SP2)
-Trainer can quickly spot mistakes many things and improve immediately. (DE3)
-More direct interaction and possibility of asking personalized questions. (SP6)
-Working with the real materials provide you more comprehensive understanding (SP5)
-You’re able to physically see and touch what you're working on. (UK2)
-Having parts really in hand, estimating weight and manageability. (DE6)

5.5.2 Advantages of using XR method

The participants stated that using XR method has some advantages for instance it makes interaction with machine easier, allows content customization, make trainees more comfortable without fear of failure and injuries, do not interrupt production process, and finally allows remote training and individualized learning. Some quotes from trainees given below;

- It's easier and more comfortable way of interacting with the machine. (PT7)
- Got a better understanding of the machine before I worked with it. (UK10)
-Structured; you get a good impression and feel prepared to go to the machine. (DE3)
- Lots of potential for content customization. (PT9)
-Individualized training, interaction with the environment without risk, familiarization with materials, visual and auditory support. (SP8)
- Immersion and realism, hands-on learning without fear of failure, immediate feedback. (SP2)
- It is not necessary to stop production for the training to take place. (SP4)
- There's no risk of injury or damaging the equipment. Learning can take place without interfering with the actual machine. (SP5)
- Being able to conduct training remotely. Multiple students can practice simultaneously. (SP9)
- Being able to interact with a machine that you don't physically have available. (SP10)
- Remote training without equipment. (SP14)
- VR allowed the operation to happen in any environment. (UK14)

5.5.3 Limitations of using Hands-on training method

Some limitations of using hands-on training methods were mentioned by the participants. They stated that hands-on method lacks repetition and improvement, independent reflection and individual practical exercise. Some participants quotations are given below;

-Not repeatable; you forget things faster because you can't repeat without trainer. (DE3)
- Need more time for independent reflection to recall learned knowledge. (DE4)
- Need to include a practical exercise. (PT2)

-Need to have more time with the machine to become more familiar. (PT3)

5.5.4 Limitations of using XR method

The participants noted certain limitations in utilizing XR methods based on their specific experiences. These limitations include reduced interactivity and visual quality of content, a lack of multilingual options, unfamiliarity with the technology, tactile limitations of XR technology, and spatial considerations. Here are some sample quotations from participants:

-Should be more interactive, information, graphical content should take advantage of VR capabilities. (PT9)
- Option to choose language for explanations and text. (SP7)
-Implement all the steps of the process, including auxiliary machines and various cases and problems that might arise. (SP11)
-Being unfamiliar with XR controls can be distractive from the learning outcomes of the training (UK5)
-More open space to walk around. (UK7)
-To get a basic feeling and to learn procedures great, but not good to learn exact parameters. (DE2)

5.6 Using XR method as a complementary tool

The participants opinion about using XR method as a complementary tool of practical training was inquired. Most of them revealed that XR method could be used as a complementary tool to enhance the practical training by decreasing safety concerns, allowing machine familiarity and action practice, remote and flexible training, time and cost saving, and increasing information. Some example quotations of participants are given below.

-More information could be presented in the VR world and even more interactive. (PT4)
-Things that can't be done hands on could be set in the virtual. (PT6)
-It's easier to repeat the training the VR and the hand-on approach gives more space for questions and more information. (PT7)
-It's safer with XR (PT8)
-I see the opportunity introduction to equipment/procedures with VR and less time spent on onsite training. (PT9)

-Yes, if the virtual training comes first, the operator will feel more confident during the machine-based training. (SP1)

-Significantly greater self-confidence / familiarity with the machine, confident learning of movements in the space around machine. (DE4)

-Practicing in VR until internalizing the process, and then performing it on the machine under supervision to appreciate the real details that VR hasn't reached yet. (SP3)

-With VR training, you can safely practice until the steps of the process become automatic, and with machine-based training, you see the actual reality of it. (SP11)

-It is a complementary experience and is safe place to try new process. (UK6)

-The possibility of making mistakes. (SP14)

-Although VR comes close to reality, it's always advisable to combine both methods, especially for critical operations. (SP16)

-It can be done remote and at individual pace. (UK1)

-Virtual training would be very useful and informative first step in machine training allowing the hands-on element to be targeted to specifies. (UK5)

- Familiarity with the machine; actions are known and practiced, thus more time for other information on the machine. (DE6)

-XR-hands on is a great route to follow. (UK10)

-You can do the training anywhere, & you don't have to have the machine to learn about. (UK11)

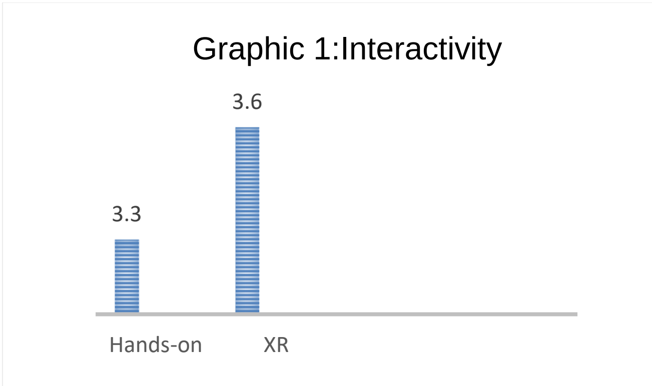
-Time saving, local component; no downtime of the machine during training. (DE1)

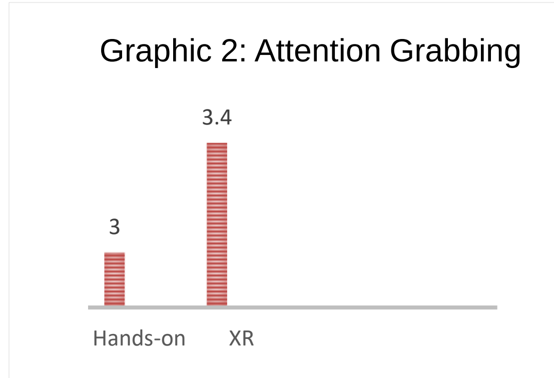
-Yes, if a trainer is available for follow-up questions, it is a good preparation; less costs, -

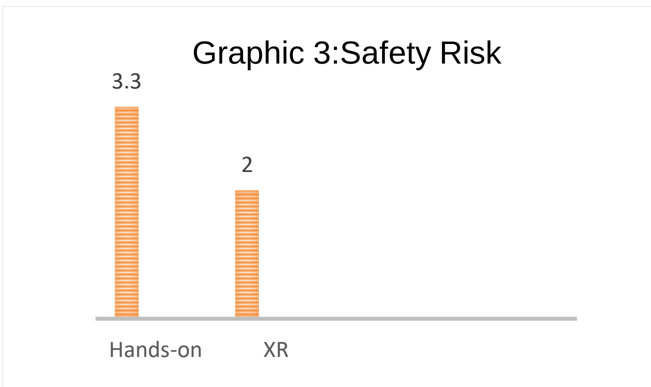
-Faster and more flexible training; repeatable; you can't damage anything. (DE3)

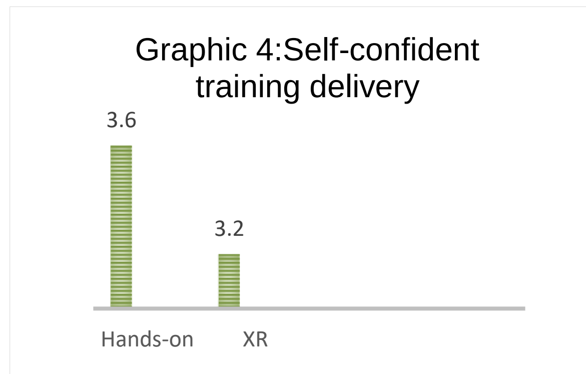
5.7 Trainers' feedback on the comparison of hands-on and using XR tools

Trainers answered the feedback questionnaire after completing the training. Some questions were asked to understand their point of view on interactivity, grabbing attention of trainers, safety risks and feeling confident while delivering the training. Based on their answers, average scores were calculated for each field. The minimum score is 0 and the maximum score is 4 for each field. The following graphics has been created to show the results visually.









Based on the reported data from trainers, the XR method appears to be more interactive and successful in capturing trainees' attention during the training. Additionally, trainers noted that the XR method offers a more secure environment for practical training. However, despite these advantages, trainers still express a higher level of confidence when delivering hands-on training.

The trainers also shared their opinions on the advantages of hands-on and XR methods. Some advantages of the hands-on training method are given with the trainers' direct quotations below.

- Hands on training is more “fluid”, in a sense that training can be more easily adapted to the trainees. It is also quicker to do for bigger audiences, since multiple people can undertake it at the same time. The time needed to run this training method is also fairly constant, since the trainer will usually take the same time, whereas for XR can take longer or shorter depending on the trainee. (T1)

- better feelings of the tasks because of manual handling (T4)

- detailed view of the machine and actual presentation of the steps. Ability to ask questions. (T5)

Additionally, the advantages of the using XR are highlighted as;

- Besides the obvious benefits in terms of H&S, XR training is an easier approach to begin with. It also provides a more stress-free environment since there is no danger of damaging the actual machines. This allows the user to perform operations that would be dangerous to perform live, as many times as needed before passing on to the real thing. XR training can also be repeated as many times as needed, in order to increase understanding.

XR training does not need a machine to be used for it, reducing the costs of training greatly.

One key issue in XR training is that it's effectiveness is directly related to the quality of the scenario, and its effectiveness needs to be measured in a case-by-case basis. (T1)

- no powder contact + fast + no PPE needed + reproduceable +depends strongly on the quality of the VR program. (T3)

-can prepare the basic know-how of the trainees, no "crushes" during the training will happen. (T4)

-removes hazard, removes conflict of machine availability. (T5)

The trainers were also inquired about usability of the XR tools in the practical training, 100% of them answered yes. Additionally, in average, they thought that 50% of the practical hands-on training could be replaced with XR tools.

5.8 Virtual Roundtable Results

The validation of the pilot results was robustly undertaken through national virtual roundtables, engaging participants with diverse backgrounds. Among the participants were those who had previously attended AREOLA trainings, and others who encountered the AREOLA project for the first time. The content analysis reveals a generally positive outlook on the AREOLA project, emphasizing its potential for improving PBF-LB operator training through practical learning, cost savings, and broader organizational impacts. The responses also highlight the need for a balanced approach, combining virtual training with live demonstrations. Some quotes from attendees are given below.

-"Can be useful for learning how to work with PBF-LB systems independently of their location!"

- "Very good opportunities in future-oriented production"

- “Less machine occupancy due to training in VR”

- “It introduces an extremely powerful training tool. Enables more autonomous and guided training.”

Additionally, participants who attended the AREOLA training perceive the course as beneficial for practical application, supporting training efforts, enhancing current work in 3D printing, and providing advantages for future career development in the field of additive manufacturing. There is also acknowledgment of the course's role in knowledge acquisition and broadening the understanding of additive manufacturing possibilities. Some quotes from participants are provided below.

- “You can understand a lot from the information you received and apply it to your everyday life, be it maintenance or repairing simple things on a 3D printer.”

- “In the field of components, this is practical for future production, as you already have prior knowledge.”

- “Good to know possible applications; Gained an overview of the possibilities of additive manufacturing.”

-“Parts of the training could be replaced by a virtual environment and material could be saved.”

-"You have acquired knowledge that can be used in 3D printing, you know several processes to manufacture components better/faster.”

The participants indicate that many possible topics may be delivered via XR tools in PBF-LB operator training, with mentions of safety, optimization, and application to diverse areas within the field of additive manufacturing. Refer to the following quotes for some feedback from attendees.

-“Powder types, machine troubleshooting”

- “You can check and optimize certain work steps in advance.”

- “AM is very broad and has many other sub-topics, whether in process utilization or equipment calibration/maintenance.”

- “In my opinion, XR training will be applied in a wide variety of areas, such as welding, machining, CNC and others.”

Finally, the roundtable participants found the project interesting, and some expressed their intention to follow the project results. Additionally, others mentioned that they would visit the project website if required, indicating a positive reception and ongoing interest in the project's developments.

6. Discussion

XR technologies have primarily been used for practical training, emphasizing hands-on tasks common in industrial use. However, further research is needed to explore how XR can be integrated into training programs to complement and possibly even replace traditional training approaches [11]. To fill this gap, this report compares the effectiveness of the XR method with traditional hands-on training. The analysis of results for learning outcomes of the training programs indicate that, there is no significant difference between the hands-on training method and the XR training method. The trainees' performance on the assessment found quite similar results. This implies that both methods are equally efficient in terms of acquiring the skills and knowledge defined in the learning outcomes, and it's suggested by the trainers that 50% of the practical training program of PBF-LB operator qualification might be conducted using the XR tools.

The analysis of feedback scores from trainees revealed a notable finding — there was no significant difference in the perceived effectiveness between the hands-on and XR tools methods. This result suggests that trainees viewed both methods similarly in terms of pedagogical effectiveness, interactivity, encouragement to learning, and confidence-building. This alignment in perception emphasizes the potential of XR tools as an equally viable and effective alternative to traditional hands-on methods. Additionally, based on the analysis of results, age and previous usage of XR tools do not significantly impact users' perception through the XR method. Therefore, the method might be used with various ages and does not require high technical knowledge or skills to manage the XR tool.

Furthermore, participants articulated various advantages associated with using XR tools including the facilitation of individualized and self-paced learning experiences, the potential for remote training, a reduction in both time and cost associated with training programs, and a preventive measure against harm or damage when encountering machines for the first time. Additionally, the observation that the use of XR methods does not disrupt machine working and production processes emerged as another significant advantage appreciated by the trainees. The perceived effectiveness and the recognition of several advantages are promising for the integration of XR tools into training methodologies.

Despite the evident advantages of integrating XR tools into training, participants highlighted certain limitations that warrant consideration. An essential prerequisite for effective XR training is the development of the XR tool itself with good quality and high resolution. This underscores the importance of investing in the technological aspects of XR to ensure a seamless and immersive learning experience.

Moreover, despite the quantitative results, analysis have shownthat having previous experience with XR tools did not give any advantages to participants over those that had no experience with the tools. It is important to note that lack of knowledge or familiarity among trainees with these tools might be a potential barrier to effective learning via XR. This observation emphasizes the need for comprehensive training programs that not only incorporate XR tools but also provide adequate orientation and guidance for users.

Additionally, participants pointed out the significance of a well-organized training environment, highlighting the necessity for sufficient space to accommodate movement and walking during XR sessions. Failure to meet these conditions may negatively impact the effectiveness of XR-based training. Addressing these considerations becomes pivotal in optimizing the implementation of XR tools, ensuring that their benefits are maximized while mitigating potential challenges.

Not only are the trainees satisfied with the use of XR tools in practical training, but the trainers are also pleased with the experience. Trainers commend the interactivity, safety, and effectiveness of XR materials in capturing trainees' attention. They emphasize the significant advantage of trainees acquiring fundamental information and practical know-how before engaging with actual machinery, providing valuable preparatory experience. The ability for trainees to repeat exercises as needed to solidify knowledge and skills is also highlighted by trainers. These collective advantages are regarded as incredible opportunities for enhancing the overall training process. As we explore the perspectives of both trainees and trainers, it becomes evident that the integration of XR tools not only meets the satisfaction of learners but also contributes to the efficacy and efficiency of the training environment.

Engaging participants in national virtual roundtables provided valuable insights into the use of XR tools in AM training, contributing significantly to our understanding. Notably, the majority of participants endorsed the findings derived from the pilot results, emphasizing XR tools as innovative and powerful assets for delivering training.

Furthermore, participants articulated several advantages associated with XR tools, including the crucial aspects of enhanced safety, heightened learning autonomy, and a notable reduction in the overall cost of training. This affirmation of the benefits underscores the potential transformative impact of XR technologies on training methodologies. More importantly, participants also expressed a forward-looking perspective, predicting that the widespread adoption of XR technologies will lead to an increase of the training opportunities and access to these training materials.

7. Conclusion

In conclusion, the findings from the practical pilot training suggest that implementing the XR method in the practical training of PBF-LB machine operators is a viable option. This method could be integrated into training by either delivering complex and risky tasks exclusively through XR or by providing trainees with essential information before they engage with the actual machine. By doing so, the approach aims to prevent accidents and injuries, and it also allows trainers to allocate less time to delivering basic information.

However, it is essential for training providers to ensure that trainees possess the necessary knowledge of using XR technology. To achieve this, providers can offer guidelines, instructions, or demonstrations to familiarize trainees with the technology. This proactive approach ensures that trainees are well-prepared and proficient in utilizing XR tools before engaging in practical training sessions.

Considering the findings of the pilot studies, some recommendations are listed below;

- Develop XR tools with excellent quality and high resolution.
- Familiarize trainees with XR tool usage, navigation, and control before the training.
- Ensure sufficient space for immersive XR training activities.
- Integrate and use XR methods before starting with hands-on training to enhance the learning progression.
- Utilize XR methods for training in high-risk environments or scenarios.

These invaluable results from the pilot testing in AREOLA can be of significant benefit to VET providers or other institutions providing VET such as higher education to integrate XR tools into practical training by following the recommendations of the report. These results will also be used to revise the existing blended learning guideline (IAB-95) in project deliverable 5, namely "Blended Learning Guideline for Implementation".

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