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Design and development of an authoring tool for XR-based Engineering Training

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Abstract

Interest in using AR and VR in education for improved learning and retention is growing. However, creating effective XR instructional content is challenging. To boost XR adoption in education, user-friendly authoring tools are essential. This study presents HELP XR, an authoring tool tailored for XR activities. Adopting an action research approach involving the user in an agile development process, this paper presents the architecture of the authoring tool, and examines the challenges associated with designing XR-based training and the inherent complexities it presents for authoring tools.

Keywords

user-centred design, augmented reality (AR), virtual reality (VR), interaction design, agile development

1. Introduction

Extended reality (XR) technologies have emerged as a potent tool for training in the manufacturing sector [1]. Immersive XR training has shown promise in improving worker performance and increasing engagement [1]. XR encompasses two distinct subcategories, namely Augmented Reality (AR) and Virtual Reality (VR), each with its own continuum [2]. These technologies have garnered significant interest, particularly in the realm of training and education. AR has reached a level of maturity that permits meta-analyses on learning outcomes [3]. VR, on the other hand, has been extensively explored, resulting in numerous literature reviews on its educational applications [4, 5, 6]. Notably, these technologies, especially AR, are deemed capable of supporting experiential and active learning [7]. In addition, training based on an AR experience allows for the further training of employees and learners without the need for additional capacity [8]. However, the widespread adoption of these technologies faces a hurdle in the form of technical complexities associated with creating customized VR experiences for students [9]. To overcome this challenge, the development of appropriate authoring toolkits holds the key to optimizing the use of XR in education. The research outlined in this paper aims to address this need for enhanced authoring tools and serves as the motivation behind this study. This article aims to introduce a digital system that enables the creation of XR training experiences without the need for programming skills. The system aims to make these experiences accessible on both VR and AR headsets. The article first presents the design methodology adopted, which is based on an agile approach with participation of the different stakeholders. It then focuses on discussing the specific challenges encountered during the development of

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this system in regard to the reaction and feedback provided by users. The following section provide findings from related works before outlining the methodology employed in the third section. It will notably present the action research paradigm adopted for this research. The fourth section presents the authoring tool design and architecture, including technical and functional specifications. The fifth section discuss the feedbacks of the learners and instructors, while the sixth section discuss the challenges and limitations identified in terms of technical, functional, and usability aspects. Finally, the conclusion summarizes the findings and presents future perspectives, including the potential utilization of standards for various features.

2. Related Work

While XR technologies hold promise for educational purposes, the process of creating XR experiences remains challenging for various reasons [10]. The facilitation of content creation for XR in the educational context is an emerging topic that builds upon efforts to validate the value and feasibility of XR in education. A recent workshop organized by the ARETE project sheds light on this issue [11]. Designing interactive AR/VR experiences necessitates striking a balance between the skills and resources required to create the experience and the desired level of fidelity [12]. Authoring tools aim to empower users without specific design or development skills to create AR experiences [12]. Similar to other software tools, AR/VR authoring tools must meet two important criteria regarding the user interface: the "threshold" and the "ceiling" [13]. The "threshold" refers to the tool's ease of use for new users, while the "ceiling" defines the extent of what users can accomplish and the limitations they may encounter. The objective is to have a low threshold, ensuring ease of use, while still providing a high ceiling of capabilities [13]. This aligns with the first requirement suggested by [7] for educational AR authoring toolkits, which emphasizes easy accessibility. This accessibility includes the ability to import and reuse assets as identified by the systematic review of VR authoring tools [14]. This would have an impact on ease of use and satisfaction with the authoring tool [14]. The difficulty is to enough flexibility to let any instructor adapt the tool to its context while ensuring "good" XR design [10]. Despite the instructional interest in immersive technologies like AR and VR, creating such experiences remain a challenge within everyday classrooms, both in the digital and physical realms [7].

3. Methodology

Interactive applications, particularly AR, offer support for active and experiential learning [7]. However, the creation of such content requires skills that are often lacking among teachers. One solution to this challenge is the utilization of an authoring tool. Teaching content must not be only digitised, but must be communicated in a meaningful way. For this purpose, the authoring tool must allow teachers to create the right content for AR experiences [15]. This prompted the research question: How can an authoring tool contribute to the educational experience through the creation of educative content in extended reality ? To address this question, this work has consisted to design and develop an authoring tool adopting an action research approach. This approach involves a continuous learning process wherein researchers

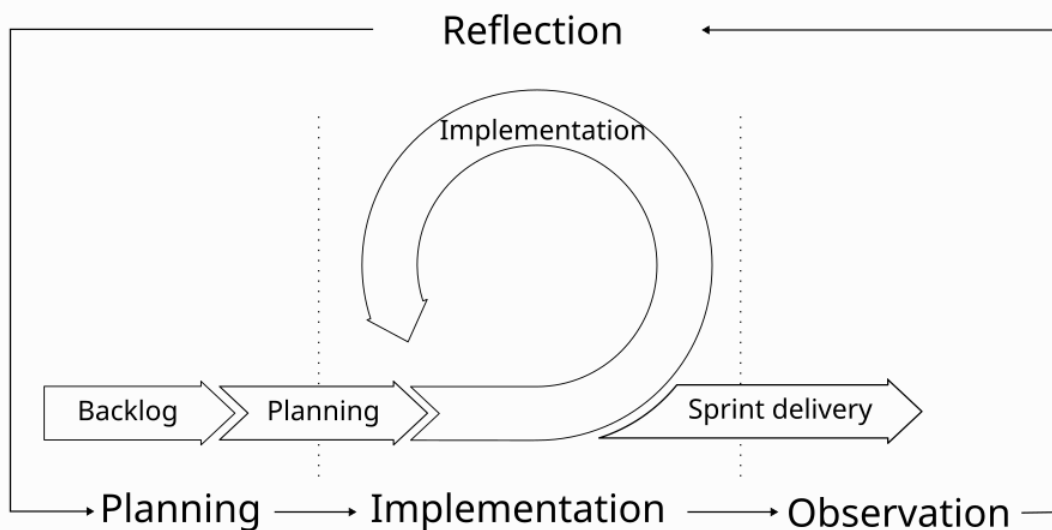


Figure 1: Schematic representation of the SCRUM methodology in action research.

actively engage and collaborate with the participants [16, 17]. The conventional action research process encompasses planning, implementation, observation, and reflection stages [18]. The implementation stages consisted to design, develop and evaluate the development with users while observation consisted to a parallel steps implying monitoring the implementation.

The development of the authoring tool followed an iterative approach, with various phases of development and testing based on SCRUM methodology [19], promoting the development of unitary functions and regular releases. The combination of the two approaches is illustrated by Figure 1. Initially, the authoring tool began as a static application installed separately on AR and VR headsets. As the project progressed, the system grew in complexity, approaching the architecture of the intended final product. Content visible in the headsets were dynamic, meaning remotely editable without installing a new version of the application on headsets.

Although the authoring system aimed to be generic, similar to generic-purpose VR authoring tools [9], it was necessary to define a specific use case to assess its relevance for different potential users. The chosen case study to evaluate the feasibility and benefits of an XR authoring tool focused on training individuals in the use of a laser cutting machine. The participants in the study encompassed four types: developers who co-created and programmed the platform, learners who participated in the testing campaign, instructors who supervised the tool's usage in a pedagogical context, and researchers who served as co-creators and managed the development process in the role of product owners. The researchers also assumed the role of instructors to gather feedback and observe user behaviour. Table 1 summarizes the different roles play by each one in this work.

Regarding the action research approach, the implementation stage consisted of developing the authoring tool with developers and evaluating it in the context of teaching laser cutting machinery operation to learners and creating instructional content with instructors. The

Table 1

Roles played by each stakeholder in action research and scrum methodology

SCRUM roles	Research action roles	Stakeholders
Product owner	-	Researcher 1
SCRUM master	-	Researcher 2
Developers team	Developer	Computer science trainee
End user	Learners	Engineering students
	Instructors	Engineering teachers and professional
	Instructors	Researchers
	Observers	Researchers

observation stage involved mainly observing and collecting feedback during the evaluation with learners and instructors, using questionnaires and control task observation (A/B test and objective-based application exploration), respectively. The reflection stage cross-referenced these observations with technical aspects related to the development of the authoring tool.

4. Results

The primary use case of this tool is to use Extended Reality to both teach laser cutter handling in-person as well as allow self-training without being in the lab with machine. In references to the hybrid learning, the authoring tool has been named HELP for Hybrid Extended Learning Platform. The authoring tool caters to two primary user groups: trainers and learners. Trainers utilize the tool to create XR content for use in courses, while learners utilize the XR system, which may involve either AR or VR headsets, to acquire task-specific knowledge. As mentioned previously, it is crucial that the tool does not necessitate programming skills from trainers. Instead, trainers should be able to upload new 3D elements into the tool and define points of interest, interactions, and augmentations. The aim is to contribute to the development of a new class of tool that enables high levels of interaction without the complexity associated with class 5 tools [12] that gather game engine such as Unreal Engine or Unity. However, the authoring tool does not integrate 3D modelling capabilities, as it is assumed that other software, both open source and commercial, already fulfil this function efficiently. The added value of the authoring tool lies in facilitating the creation of immersive environments. As previously mentioned, the tools aim to offer XR features, encompassing content creation for both AR and VR. To achieve this, two different head-mounted display (HMD) technologies were utilized during development: Microsoft HoloLens and Meta Quest 2. The web app, accessible on desktop/laptop, was used for designing the training content. While responsive design allows access through smartphones, certain functionalities may be limited. According to the user group, the primary purpose of the web app differs. At one hand, learners use the web app to connect to user accounts, pair with an HMD, and view statistics. It mostly targets smartphone accessibility. On the other hand,

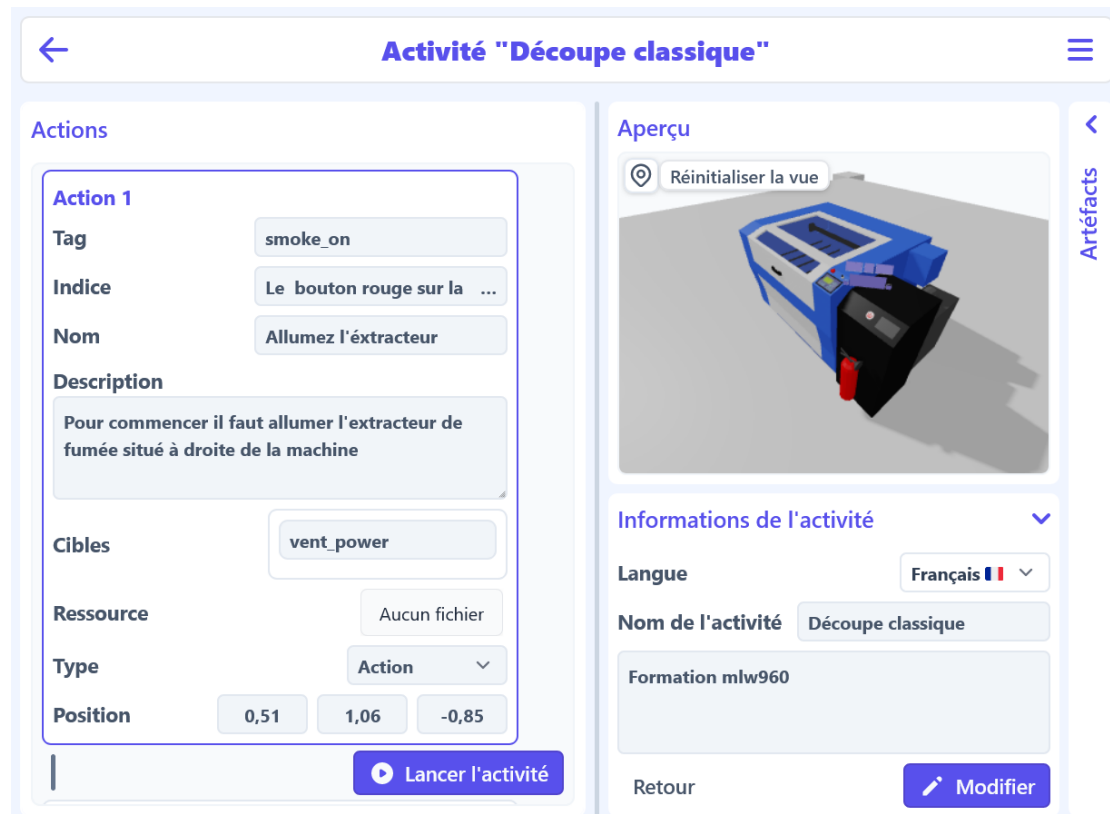


Figure 2: Web application interface for XR training design.

trainers will use the web interface to prepare the training (Figure 2), design the experience, manage access and explore usage statistics.

From a technical standpoint, the AR and VR client applications on the HMDs were developed using Unity. Due to distinctive specificity of the HMD, one client has been created for VR and another one for AR. The web app front-end interface was created using the VueJS framework [20], supplemented by additional libraries such as three.js [21], to visualize and design the 3D environment utilized in AR and VR. Both AR/VR client and web app communicate with an API done in Python using FastAPI and a Postgres database. Figure 3 provides an illustration of the system architecture. As the client on the HMD has to communicate with the API to retrieve teaching scenarios, it is dependent to a constant connection to internet.

Based on this system architecture, it is possible to provide a more detailed description of the tool's usage, considering the user's interface and role. From the learner's perspective, the user accesses the web application through a mobile or desktop web browser. Once connected to the application, they have the option to pair their head-mounted display (HMD) to their account, granting them access to the available XR training content (illustrated by Figure 4). If the user possesses an AR HMD, such as HoloLens, they can directly interact with the physical machine while wearing the device. Conversely, if they are using a VR HMD, they will only interact with

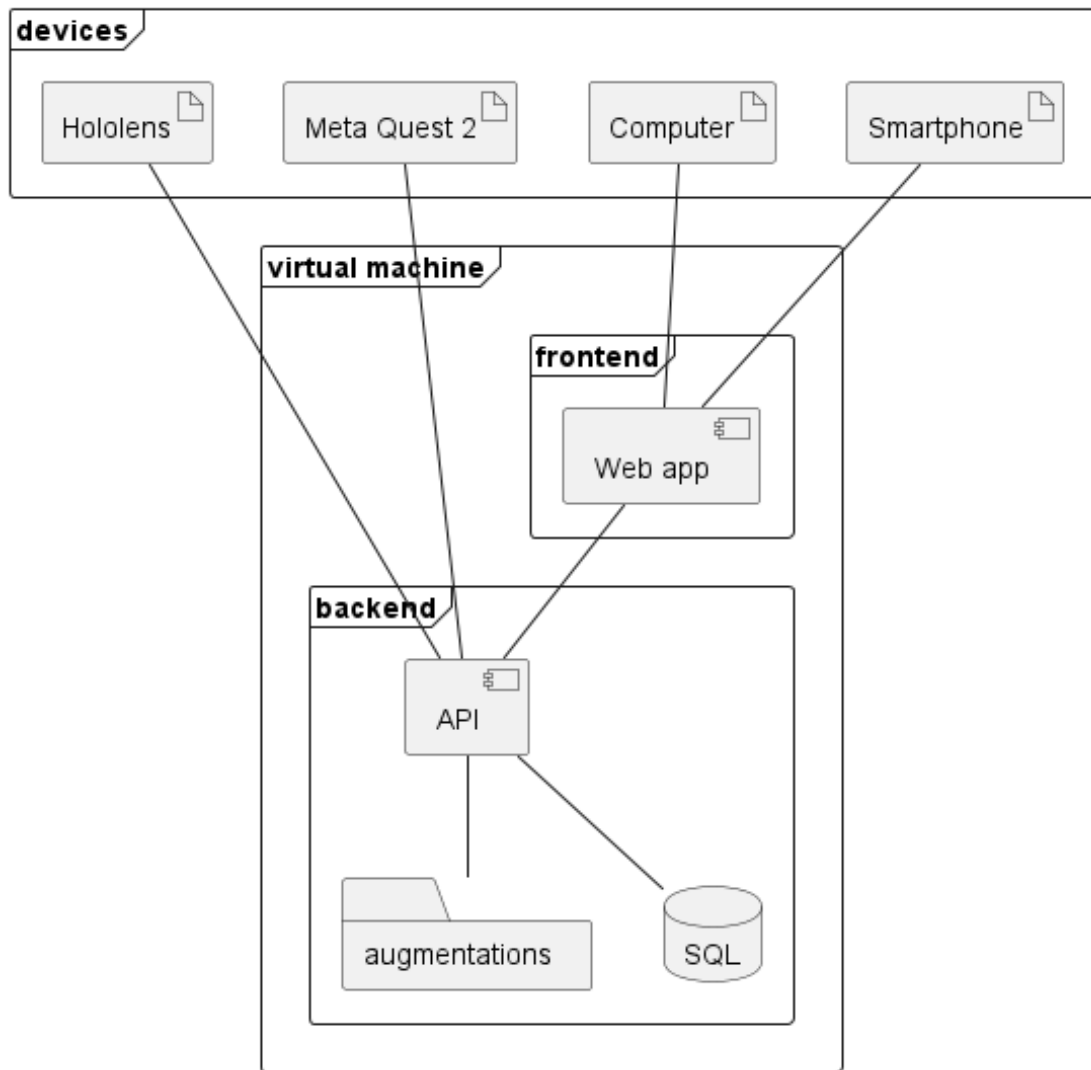


Figure 3: Architecture of the designed authoring tool.

a virtual representation of the machine. This specific use case is illustrated in Figure 5.

Regarding instructors, the system offers a broader range of functionalities and use cases. As designers of XR content, they primarily utilize the web application to create the environment, define model behavior, develop XR training modules, previsualize the appearance of the training and augmentations, and analyze data on system usage. The XR head-mounted display (HMD) is optional for instructors, serving as a means to further verify the behavior of the training and ensure proper alignment with the physical world in the case of AR HMDs. One key aspect of creating a valuable and enjoyable augmented reality experience is the accurate positioning of indicators and points of interest on real-world objects. Achieving this requires the creation of a virtual environment and the definition of markers in QR code format that can be precisely

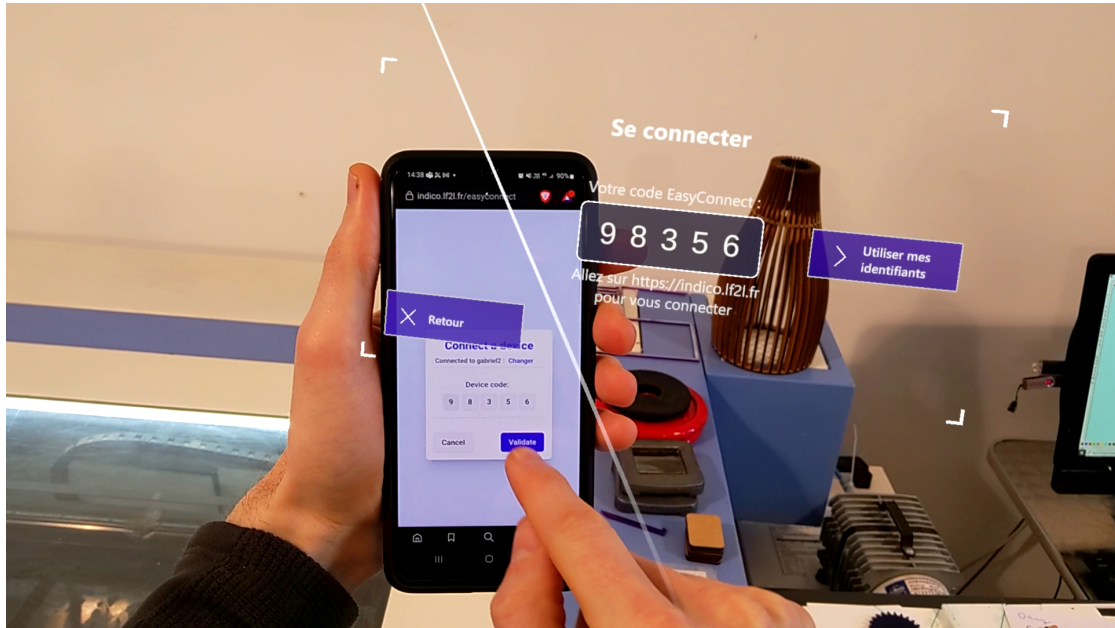


Figure 4: Capture of the connection procedure.

positioned on the corresponding objects in the physical world. Figure 6 illustrates this specific use case of the authoring system for instructors.

5. User Feedbacks

The main users of the abovementioned authoring tool (HELP XR) are the instructors and the learners. In order to evaluate it, experimentations have been conducted to get the feedbacks of these users.

5.1. Learners Feedbacks

The experimentation with learners was two-fold. First, they had a training phase to learn how to use laser cutting machine using AR before answers 6 questions. Second, they passed an evaluation phase where they reproduced what they learn on the machine and answered 3 additional questions. The entire experiment took around 15 minutes per participants, including around 5 minutes using AR, which reduce fatigue issues for the experimentation. Table 2 lists the questions answered on a 5-item likert scale. The former group of questions was about the perceived utility (Q1), the perceived ability to reproduce the process alone (Q2), the clarity of the process (Q3), the need of additional explanation (Q4), the ease of use (Q5) and the clarity of the interface (Q6). Figure 7 summarizes the answers. In overall, all the questions were evaluated positively by a large majority of participants. The confusing results about need of information is due to an inversion of the scale, 86% of learners (31 persons) needed little or no additional

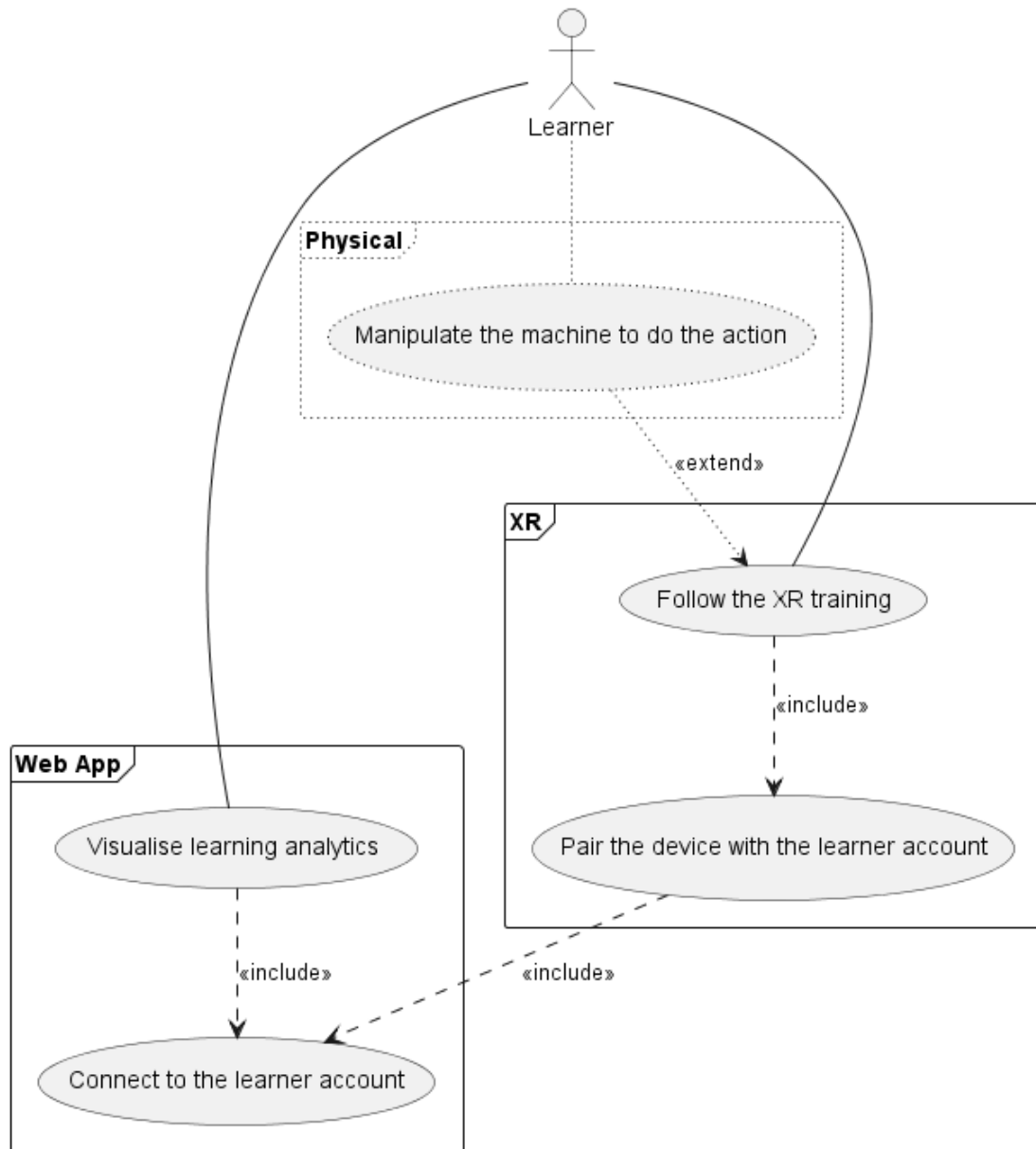


Figure 5: Learner use case diagram.

information. The main interest for this article is the ease of use and the clarity of interface that receive positive feedback from respectively 94% and 89% of learners.

The latter group of questions was the perceived utility after evaluation (Q7), the adequacy of the training process for using the machine alone (Q8) and the self-performance (Q9). Figure 8 illustrates the answers. The self-performance had the lowest rate of positive answers in comparison to other questions with 65% of positive evaluation.

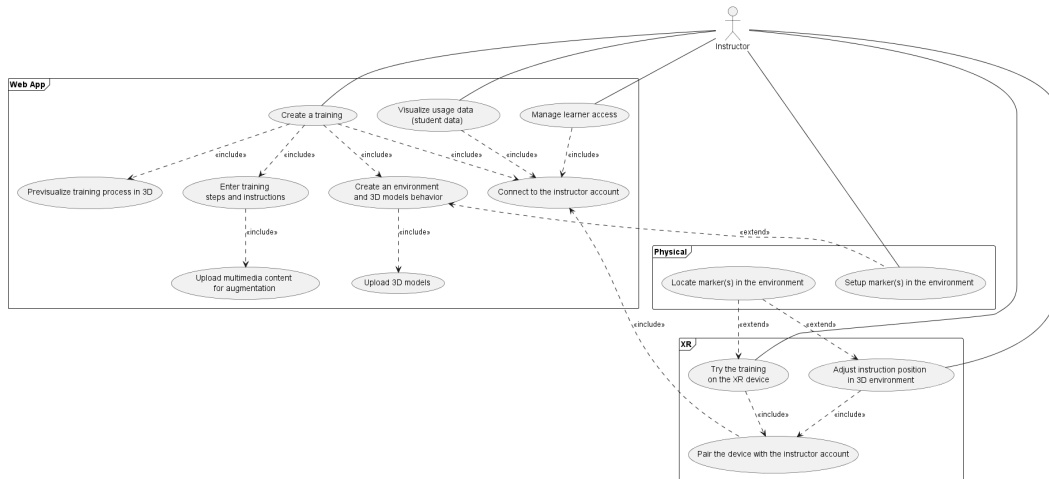


Figure 6: Instructor use case diagram.

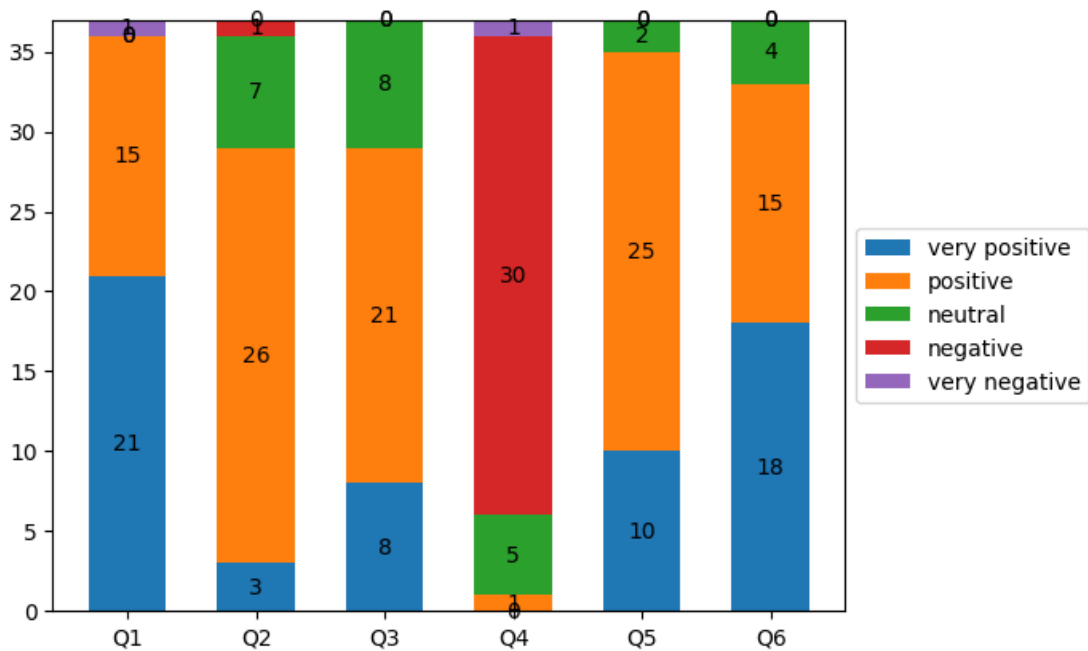


Figure 7: Breakdown of answers to post-training questions.

5.2. Instructors Feedbacks

With regards to instructors, the initial experimental study concerned the accessibility of web interfaces. The ambition was to identify the interfaces best suited to profiles less familiar with XR content creation. Two exercises done with instructors was A/B testing with selected pages and free exploration with mission. One of the main feedbacks was the inconsistency and

Table 2
Questions

ID	Phase	Learners evaluations questions
Q1	Training	How useful is the application for learning how to use the machine?
Q2	Training	How confident are you in your ability to perform laser cutting on your own?
Q3	Training	How clear is the learning process to follow?
Q4	Training	Following training, how often did you feel the need for an explanation from an instructor?
Q5	Training	How easy is it to use the application?
Q6	Training	How clear and well-structured is the application's interface?
Q7	Evaluation	How useful do you think the training was in enabling you to carry out the cutting task on your own?
Q8	Evaluation	To what extent do you think the training process was sufficient to carry out this task?
Q9	Evaluation	How would you rate your performance on this task?

incomprehensibility of the terms used in the authoring tool.

6. Discussion

This work has developed and implemented the HELP XR authoring tool among learners and instructors. According to feedback from users and critical reflection from researchers involved in the project, as implied by the research action approach, the response was relatively positive. A large majority of learners still consider it useful even after the reproduction task and find the training using the tool sufficient. Instructors were generally satisfied despite difficulties due to the vocabulary used on interfaces and some poorly positioned buttons. Regarding the research question, the tool seems promising for contributing to the educational experience through educational content creation. However, this experimentation raises various challenges regarding the system architecture and features, training design, and user interfaces.

6.1. Designing the authoring system challenges

As previously emphasized, the designed authoring tool aims to generate content that is accessible on both AR and VR platforms. This necessitates considering each experience independently, as they have their own specificities, while ensuring that the required specific data is collected [2]. In the initial version of the system, data were successfully collected and utilized in both AR and

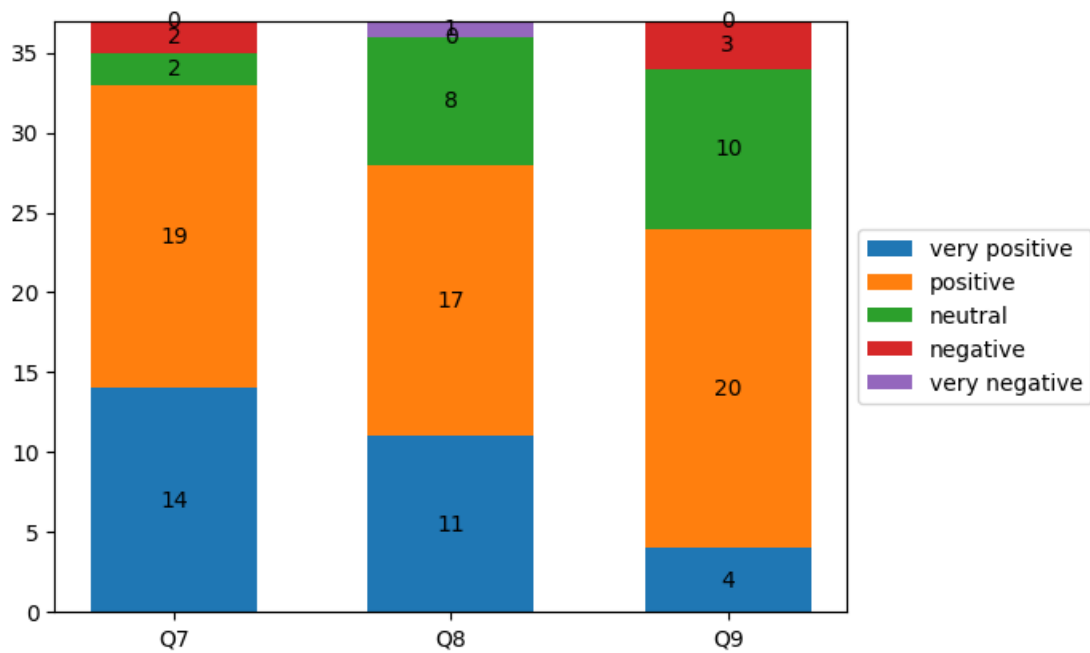


Figure 8: Breakdown of answers to post-evaluation questions

VR without local storage. However, this raised the need to clearly define the data structure for describing information, augmentations, positions, and 3D models at each step. It is crucial to establish a correct data structure as an erroneous one can impact the system's future evolution and interoperability. One potential solution is offered by the ARLEM standards [22], which provide a data structure for AR applications. However, these standards are currently limited to AR. To the best of the authors' knowledge, the INOOVAS ontology [23] is the only attempt to provide a data structure for both AR and VR, however, literature reviews [14] indicate that ontologies have not yet been employed in VR authoring tools. A second challenge relates to the organization of data pertaining to tool usage. The initial version collected the time taken to complete a step in the learning process for a single student. However, this ad hoc approach to data collection was imprecise and incompatible with learning processes that involve iteration and roundtrip among different steps. As highlighted by [11], xAPI presents a relevant technology for advancing data collection in learning analytics. It enables the collection of temporal series with codification of the actions performed. The next version of the tool will integrate xAPI recommendations to gather more precise data that can potentially enhance our understanding of student behaviour when using XR tools. A third challenge involved accurately positioning points of interest on a machinery. In the case of the laser cut machine, the buttons were in close proximity to each other, making even a slight deviation of one centimetre potentially hazardous. Two closely positioned buttons may have distinct functions, such as positioning the cutting head at the origin and initiating the cutting operation. To address this issue, markers were used during the initial setup phase to precisely position an invisible replica of the physical

machine, including its buttons. This ghost 3D model assists in positioning the indicators for points of interest, which in turn support instructional guidance. A fourth challenge pertained to simulating the actual functioning of the machine. While AR does not require a logical model of the machine as learners work with the real equipment, VR tools demand significant effort to create a realistic experience that allows learners to interact with the machine. The initial solution involved scripting the machine's behaviour using the LUA language [24]. However, scripting and programming requirements pose accessibility barriers. To mitigate this challenge, the decision was made to implement a block-based interface [25] to simplify the modelling process.

6.2. Training Design Challenges

Outside technical perspective to make the authoring system possible, the implementation of the tool to teach usage of laser cut machine raised issues related to training design. The main one concern how the taught sequence/process is divided into steps. The chunks have to be understandable, meaningful and well introduced by the context and the previous steps. Basic steps such as opening the cover of the machine can constitute one step to eventually explain how open it but repeating it several time in the process might impact the learner interest and the usefulness of the tool for learner. On the other side, steps should consider the right level of prior knowledge. During the teaching phase, one step has generated issues because a technical terminology was not defined and the video that was supposed to support the step was not understandable with prior knowledge of the machine. The step could have been split into several steps to introduce position of parts, there name and function before expect the learner interact with it. This is confirmed by the learners' self-evaluation of their performance. Despite positive evaluations of the tool, its content structure and, above all, an initial positive perception of their competence, they evaluate their performance more moderately. Future work will explore the data from the learners' experiments in greater depth through a comparative study.

6.3. Interface Challenges

The aforementioned instance involving video issues and comprehensibility has brought up interface and ergonomic concerns. It is necessary to study the optimal video size and, more broadly, the size of augmentations in order to achieve the most legible information. Another challenge lies in ensuring a consistent experience between AR and VR. This entails establishing a shared vocabulary, aesthetics, and potentially identical button placements across the software. The initial version of the VR client was notably identified as significantly divergent from the AR experience, rendering it almost unusable and incomparable. Another aspect of user experience (UX) homogeneity is the configuration of controls for both AR and VR. Augmented reality HMD such as the HoloLens doesn't have controllers. Interactions are done with hand gesture. In order to be coherent between virtual, augmented and real experience, appropriate interaction modalities have to be predefined in VR and activated accordingly.

7. Conclusion

The article discusses the way authoring tool facilitate the creation of educational content in extended reality. The work is based on research action paradigm combined with agile method to ensure development and user participation in the development process. The aim is to identify new avenues of research concerning the simplification of XR content creation. This content creation struggle is one of the main brakes for XR adaptation in pedagogy. This article raised system design challenge, training design challenge and interface challenge based on the development of the authoring tool. Perspective of this work is would be to explore the implantation of ontology to formalize AR and VR principles and concepts in order to clarify interoperability between technologies. It is an opportunity shared by [14]. A first step would be to notably translate and extend ARLEM standard [26]. Another perspective is creating the same kind of standard to describe the way machines work to ease their simulation inside virtual environment. The cost of devices is a barrier to adoption, but content creation is an even bigger one. One possibility to provide equity and accessibility to XR technology in training would be the widespread of open-source XR authoring as it is the case in the domain of learning management system. It notably for this reason the code source of the authoring system [27, 28] and its clients [29, 30] are share on Github. However, sharing the source code, while appreciable, in no way guarantees the appropriation of the tool or the creation of a community around the project. Time has to be devoted to promoting the project [31].

The limitations of this work are mainly related to the method. The action research method is mostly subjective, although this was somewhat mitigated with questionnaires. To address this issue of objectivity, a large-scale user study using a standard evaluation scale and comparison with other AR/VR authoring tools would be required. In addition to further user studies, future work might be valuable in the field of XR environment interoperability through the exploration of standards homogenization and alignment, as well as the translation of this potential new standard into a web semantic vocabulary

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