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Authoring instructional flow in iVR learning units to promote outcome-oriented learning

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ABSTRACT

Despite the recognized efficacy of immersive Virtual Reality (iVR) in skill learning, the design of iVR-based learning units by subject matter experts (SMEs) based on target requirements is severely restricted. This is partly due to a lack of flexible ways of authoring instruction flows to arrange the learning activities in alignment with the desired learning objectives. Our research provides a workflow design enabling SMEs to author the flow of learning activities developed by the Virtual Reality (VR) developers, with an aim to enable learners achieve desired goals progressively in a virtual environment. Additionally, this outcome-oriented flow authoring utilizes a scalable learning framework that categorizes learning activities into four instructional phases: *Introduction*, *Presentation*, *Practice*, and *Application*. Such frameworks can be easily integrated into the instruction to plan a class or a series of classes to cover an entire concept or chapter. Using a welding use case, our user study evaluation with 12 experienced welders indicated positive ratings about the usefulness of such workflows for flexible planning of training scenarios. We envision adoption of such methods could facilitate greater and more efficient adoption of the iVR technologies in pedagogical settings.

1. Introduction

Due to the requirements of technical modeling and programming expertise, virtual content creation for immersive Virtual Reality (iVR) applications is primarily restricted to Virtual Reality (VR) developers (Gaspar et al. (2020); Coelho et al. (2022)). In order to utilize iVR applications for training purposes, subject matter experts (SMEs) thus rely upon and work together with VR developers to author relevant content for their courses (Walczak et al. (2020)). This collaboration, which typically happens on a contractual basis over a stipulated period, results in a packaged product at the end of the development cycle, with minimal room for variability in the final instruction design. Any demand for design modifications typically requires version change for the entire application, thereby limiting the scalability of instructions based on training requirements (Ketoma et al. (2023)). Moreover, this causes SMEs to compromise with and plan the training programs around the rigid situation. Therefore, there is a need to propose workflows that empower SMEs with control over iVR instruction planning, catering to the varying needs of learners and the learning process.

While designing educational content for conventional classroom settings, SMEs are often found playing with the flow of the learning activities and/or iterating upon existing flows to adjust the final arrangement of the instruction sequence based on the desired learning objectives. Take the case of a learning unit from Metal Inert Gas (MIG) welding training, i.e., Tee joint design in horizontal position. Some learning objectives that can be targeted from the unit may include: (A) Locate and identify joint type (Tee) and position (horizontal), (B) Understand the different Key Performance Indicators (KPIs) (distance, travel angle, work angle, speed) and their specifications for welding Tee joint in horizontal position, and (C) Perform welding on a Tee joint in horizontal position (Bowditch et al. (2017); Wang et al. (2006); Althouse (2020); Alex (2014); Jeffus (2009, 2012)). After the learning objectives are set, the choice of learning activities and their sequence may vary based on the demand of the situation. For example, depending on the prior experience of the learners, the SME may decide upon which supporting outcomes and learning activities to include, so as to ensure that the desired objectives are met. In the above case, for a novice learner, the SME may consider including the supporting outcome of understanding the basic safety regulations necessary to follow in a MIG welding workspace, and the learning activities surrounding it such as identifying Personal Protective Equipment (PPE). On the other hand, for a learner with prior experience with MIG welding safety, the supporting

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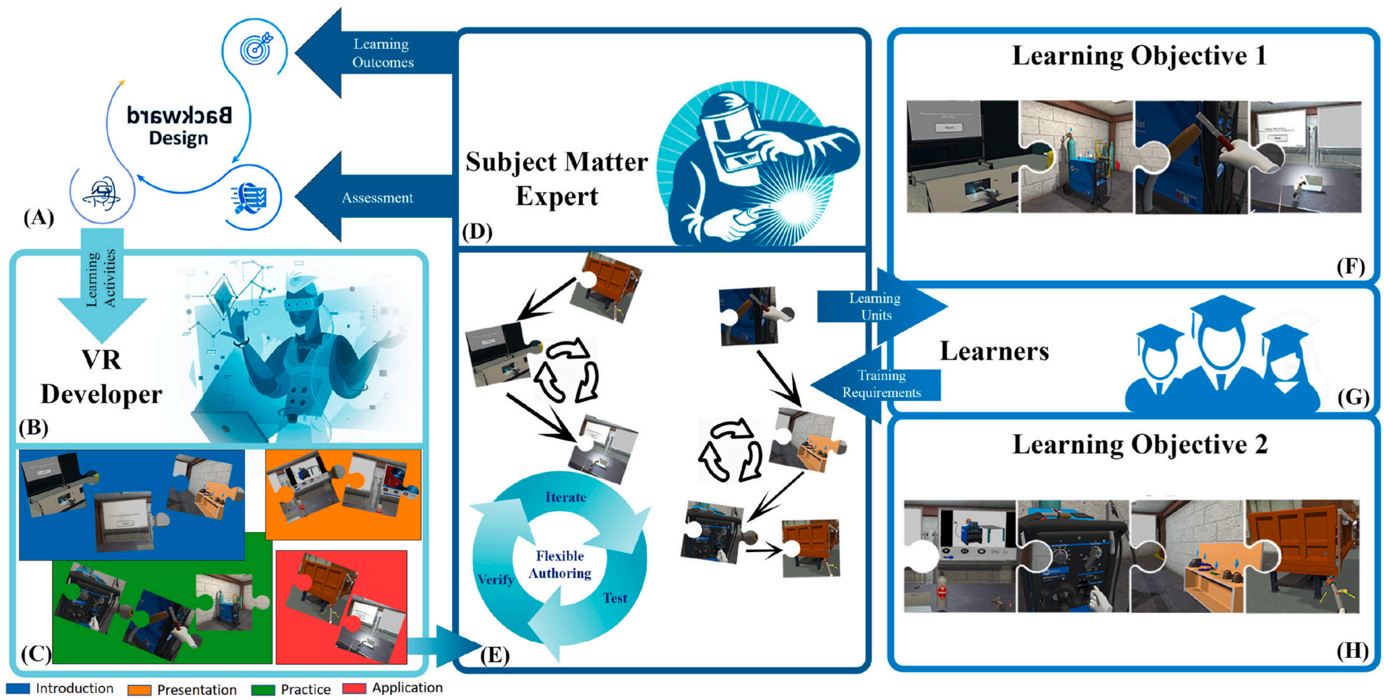


Fig. 1. System workflow design of FlowTrainiVR: (A) Based on the learning outcomes and assessment identified using the Backward Design approach, a set of learning activities is outlined to achieve the training goals. (B) These activities are developed by the VR developers, (C) grouped into four instructional phases of *Introduction*, *Presentation*, *Practice* and *Application*. These phases are color-coded as Introduction → Blue, Presentation → Orange, Practice → Green, and Application → Red, in the figures of this manuscript to facilitate comprehension of the work. (D) The subject matter experts use these activities as building blocks to (E) plan the instructional sequence for their learning units based on the training requirements. (F) The learning units, thus planned, are used by learners to achieve the (G) desired learning objectives. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

outcome of understanding safety regulations and identifying PPE might not be crucial and the SME may consider dropping it from the instruction sequence concerning the unit. Additionally, the instruction sequence can also vary based on the path of the learning scenario as deemed beneficial by the SME. The dynamic nature of the authoring of the content progression allows SMEs to take care of the learners' needs, while being able to meet the learning objectives of the course.

Considering the importance of instructional flow design and authoring, we present ***FlowTrainiVR***, the system workflow design to enable SMEs plan learning units and author flexible training scenarios targeted towards desired learning objectives (Fig. 1). The workflow stands on the groundwork design of learning curriculum laid out by the principles of Backward design which first identifies the desired learning outcomes and objectives, and then aligns the skill assessment and learning activities based on the intended learning outcomes (McTighe and Thomas (2003); Wiggins and McTighe (1998); Ipsita et al. (2022)). The proposed workflow in FlowTrainiVR begins with the development of the learning activities by VR developers based on the curriculum framing set according to the Backwards design approach. The learning activities are then handed over to the SMEs to plan the learning units based on the desired learning objectives. In our work, the learning activities that act as the building blocks for planning the learning units are categorized under the four instructional phases of *Introduction*, *Presentation*, *Practice*, and *Application*. This categorization is adopted from learning sciences based on the evidence of the instruction phases to provide a concrete framework for planning the instruction sequence and types of activities for the learning units (Yong et al. (2016); Kruse (2009); David Merrill (2002); Bybee et al. (2006)). Apart from ensuring an efficient and goal-driven learning of students, these phases, when combined together, present a scalable framework which can be utilized to design a single lesson or a series of lessons, based on the target requirements of the training process.

To enable flexible authoring of the instruction sequence, we create a graph-based flow editor, where the nodes represent the learning activities and edges represent the connectivity between them. Users can drag and drop nodes onto the editor interface from existing libraries to include relevant learning activities into the unit. The nodes have editable properties which allows further personalization based on the context of the learning. Finally, users can add connections between nodes to create the instruction sequence in the form of a linear directed acyclic graph (DAG). The sequence thus designed defines the flow of learning activities in the iVR-based learning units. Using a welding use-case and based on our prior learning rationale extracted using Backward design (Ipsita et al. (2022)), we created a representative library of 27 learning activities covering three topics in a MIG welding curriculum: (A) basics of MIG welding, including safety and welding equipment; (B) welding wire change maintenance; and (C) Tee joint design. A user study was conducted with 12 experienced welders to test the usability and effectiveness of the system components to design the instructional flow for iVR-based learning units. From the user study, we aimed to answer the following research question.

– To what extent do the system components enable SMEs to flexibly author training scenarios based on varied learning objectives?

The user study results indicated that users could successfully plan, test, verify and iterate upon diverse scenarios of learning units based on desired learning objectives. Furthermore, the subjective feedback collected from the study was analyzed to obtain design recommendations to enhance the efficiency and scope of the workflow design in planning effective iVR-based learning units.

Thus, the contribution of our work are as follows:

– the system workflow design that enables collaboration between SMEs and VR developers to facilitate pedagogically driven planning of iVR-based learning units using learning activities framed in

alignment with the Backward design approach (McTighe and Thomas (2003); Wiggins and McTighe (1998); Ipsita et al. (2022)),
- a graph-based flow editor that allows flexible composition of learning activities categorized under *Introduction*, *Presentation*, *Practice* and *Application* based on the general instructional framework, to author instruction sequence in iVR-based learning units (Yong et al. (2016); Kruse (2009); David Merrill (2002); Bybee et al. (2006)), and
- the demonstration of the workflow design using a welding use case along with the evaluation and results from a user study conducted with 12 experienced welders.

The article's structure is outlined as follows: In Section 2, relevant literature is presented. Section 3 introduces key terminology to facilitate comprehension of the work. The workflow design is then detailed in Section 4, with 4.1 providing specific insights into the implementation details. The user study procedure and its results are presented in Section 5. In Section 6, the study results are discussed in greater detail. Section 7 addresses the future potential for improvement and limitations. Finally, Section 8 presents the conclusion of the work.

2. Related work

2.1. Immersive Virtual Reality in education

In the context of the research presented in this work, iVR specifically refers to the immersive Head Mounted Display (HMD)-based virtual environments, amidst various types of VR-based environments like desktop-based, CAVE environments, and HMD-based systems. The HMD-based virtual environments are designed to fully immerse users in a simulated setting, inducing a compelling sense of presence through embodied interactions. The benefits of integrating the iVR technology, particularly in the context of education, are diverse and encompass several key aspects (Gonzalez-Franco et al. (2017); Renner et al. (2015); Daniel (2017); Price et al. (2019)). iVR enables practical learning experiences without the need for costly physical equipment or exposure to the potential hazards of actual industrial settings (Poyade et al. (2021)). The technology promotes active engagement and better retention through its interactive and immersive nature, fostering increased student motivation and interest in the learning content. iVR simulations empower students to interact with realistic 3D models and refine their problem-solving abilities within a safe and immersive learning setting. Additionally, iVR facilitates the visualization of intricate processes and abstract concepts, simplifying the comprehension of complex systems that might otherwise be challenging to grasp through conventional teaching methods. It also serves as a platform for training students in specialized skills and procedures, effectively preparing them to meet the demands of contemporary practices and bridging the gap between theoretical knowledge and its practical application. Through trial and error, students can actively practice assigned tasks and evaluate their learning experiences independently, without continuous observation and support from instructors. Notably, iVR learning environments have also shown to efficiently facilitate student assessment, providing time-series data on multiple performance metrics and interaction measures, including error rates, task completion time, number of attempts, and duration spent on specific course content and tasks, among others.

The provision of spatial and experiential learning in the risk-free iVR environments allows learners to gain hands-on experience with close-to-real learning activities while keeping the learners engaged by inducing a sense of presence within the situated learning context (AbichParkerMurphyMorgan (2021); Checa and Bustillo (2020)). Prior research has highlighted the positive impact of iVR environments on learning in terms of improved confidence, perception, knowledge, and skills in learners, which are needed to perform the activities in real workplace settings (Bossard et al. (2008)). Additionally, iVR learning reduces the usage of physical equipment, consumables, and instructor time and effort, while enabling remote instruction transfer, thus reducing the problems caused by geographical and financial constraints (Howard et al. (2021); Jan Lacko (2020)). Despite these advantages, it is still a herculean task for SMEs to adopt the technology in their training curricula to achieve outcome-oriented learning for the learners.

The creation of domain-specific iVR-based training experiences requires competencies in both programming (e.g., using Unity or Unreal Engine) and 3D modelling, as well as domain knowledge in the given field (Gaspar et al. (2020); Cassola et al. (2021)). Therefore, it typically requires the involvement of software development experts and SMEs to jointly design and structure the final product based on the target requirements. To that end, prior research highlighted the importance of systematic integration of pedagogical concepts into the design of VR learning applications to ensure effective and outcome-oriented planning and design of the learning content (Vallance (2021); Ipsita et al. (2022)). Despite the use of such effective approaches, it is usually the case that the applications that are designed and shipped to the SMEs are rarely modifiable from the original logic, which was already designed by the VR developers (Ketoma et al. (2023)). However, the adaptability of training scenarios is crucial to align with the training situation and cater to the individualized learning progress and needs of trainees (Ketoma et al. (2023); Motti et al. (2013)). This requires SMEs to have the ability to plan instructions for optimal training outcomes. As a result, the lack of flexibility in adjusting and modifying scenarios based on changing requirements poses a limitation to the utilization of iVR training applications. Furthermore, the substantial allocation of budget and time during the development process adds extra pressure to ensure accurate specifications in the initial product release, aiming to minimize the need for future iterations (Cassola et al. (2022)). Consequently, these challenges restrict the widespread adoption of iVR applications in pedagogical settings. In light of these issues, the proposed workflow for developing iVR applications for training aims to tackle the problem by granting SMEs control over the planning of learning units.

2.2. iVR authoring in education

Authoring tools for content creation can solve the problems faced in the development of iVR-based training applications to some extent by making new VR content easier, faster, and more efficient (Coelho et al. (2022); Kaskalis et al. (2007)). However, the design of training scenarios remains particularly difficult due to the low level of code reuse, which often necessitates advanced programming skills. This obstacle can be overcome by reusing content, eliminating the need to develop the same asset repeatedly when creating or editing new experiences (Seo et al. (2001); Zikas et al. (2020)). Few of the above mentioned VR authoring tools allow reuse/import of content/assets enabling VR designers to significantly reduce their effort and generate custom user experiences that would otherwise be impossible. However, the high-level componentization approaches commonly employed in these content creation tools are heavily focused on technical aspects, resulting in a high level of complexity in the content design process (Walczak et al. (2020)). This creates the requirement for knowledge engineering technicians to design training scenarios, and thus poses a challenge for SMEs to use these tools for VR training preparation. On the other hand, there has been some approaches of using machine learning methods to author curricula based on training needs. Kumar et al. generated a customized curriculum for medical students based on deep learning techniques, utilizing data analysis and classification (Kumar et al. (2022)). The curriculum is generated using a gradient decision tree integrated with naïve Bayes, and learning approach recommendations are made using a fuzzy rules integrated knowledge-based recommendation system, with experimental results showing high accuracy and precision. However, such automated methods lack SME involvement in the content creation process, which limits their utility in the training process.

User-friendly content authoring tools are crucial for SMEs to design VR training scenarios based on their knowledge. These tools can play a significant role in reducing time and effort and promoting the use of VR in training (Walczak et al. (2020)). Ziklas et al. highlights the significance of innovative authoring platforms in enabling users with limited programming knowledge to easily design virtual environments (Zikas et al. (2023)). Cassola et al. developed a method for creating semantic VR scenarios that can be used by users without advanced programming or 3D modeling skills (Cassola et al. (2021)). This approach empowers trainers and trainees to develop diverse and immersive learning scenarios for manufacturing and industrial applications, including certification. Coelho et al. introduced intuitive interfaces for developers and content creators, providing real-time feedback on how the content will be presented to end-users (Coelho et al. (2019, 2021)). This interface reduces the number of iterations required and potentially accelerates the development time of iVR applications. Wolfartsberger and Niedermayr proposed an authoring platform that empowers trainers to develop comprehensive courses within an immersive environment (Wolfartsberger and Niedermayr (2020)). This platform enables trainers to specify elements, observe procedures, facilitate practice and testing, and assess trainees' performance. VR4Health functions as a training tool that allows teachers to monitor the learning process and provide feedback to students (Fairén et al. (2020)). It collects data on motivation, interest levels, and potential issues, facilitating the formulation of relevant questions for feedback sessions. Cassola et al. introduced a solution that enables SMEs to author specific sequence procedures for trainees, focusing on simulating immersive learning environments and increasing the availability of training components (Cassola et al. (2022)). Lécuyer et al. provided a method to ease the scenario creation by enabling experts to record actions in VR to create action sequences, and then generate scenarios by utilizing those sequences (Lécuyer et al. (2020)). This approach aims to create engaging experiences for trainees. In terms of 3D content modeling for training scenarios, Walczak et al. proposed solutions that utilize domain knowledge representation techniques and the semantic web to describe content meaning in a standardized manner (Walczak et al. (2020); Jean-Luc (2009)). However, these tools have primarily been created as independent applications within specific contextual domains, overlooking pedagogically oriented approaches and neglecting their proper integration into the development cycle of iVR learning applications. Consequently, this limitation has led to a restricted adoption of such tools in pedagogical settings.

Unlike the development of iVR applications in the gaming and entertainment domains where it originated from, their effective use in professional settings requires incorporating expertise from various domains to design and implement effective training scenarios (Mishra and Koehler (2006); Mahdi et al. (2018)). To accommodate the dynamic nature of diverse training needs, Mahdi et al. propose a stepwise process for developing pedagogically oriented VR training scenarios (Mahdi et al. (2018)). This process involves teachers expressing their needs, adapting the 3D environment, operationalizing scenarios, and conducting simulation/testing. They also introduce a custom-built tool for scenario development, although its limited features compared to game engines have hindered its widespread adoption. Saunier et al. suggest separating roles in the creation of VR training environments, identifying four main roles: designer, job expert, educational specialist, and teacher (Saunier et al. (2016)). Each role actively contributes to the creation of pedagogically driven scenarios. Kavanagh et al. emphasize the use of VR learning by leveraging constructivist pedagogy and gamification in experience design (Kavanagh et al. (2017)). Keskitalo highlights the pedagogical utilization of VR in education and training, particularly through simulation (Keskitalo (2011)). Similarly, Kemanji et al. emphasize the need for specifying and developing a dedicated pedagogical model for VR usage (Ketoma et al. (2023)). Building upon the aforementioned pedagogically driven research, our method presents a workflow design that is also driven by pedagogical models. It utilizes user-friendly components and enables SMEs to plan their instructional content based on varying training requirements, aiming to address the challenges faced in incorporating VR technology in educational settings.

3. Clarification of terms

The following definitions will aid in the understanding of terminology used in this research work.

- *Learning outcomes* indicate the relevant objectives (e.g., established goals, desired understandings) that will be addressed by the system. These will be useful in determining what students will know (e.g., what critical knowledge and skills will be acquired) and what students will be able to do as a result of the knowledge and skill acquisition (Adam (2004)).
- *Learning objectives* are goals that target specific knowledge, skills, and dispositions taught in specific sections of a module (Nicholls et al. (2014)).
- *Learning plan* is a description of how to design the learning experience and instructions to achieve the desired outcomes in learning (Nicholls et al. (2014)).
- *Learning activity* can be defined as a specific interaction of learner(s) using specific tools and resources, orientated towards specific outcomes (Gráinne (2007)).
- *Learning module or unit* is an organized collection of teaching materials consisting of behavioral objectives, a sequence of learning activities, and provisions for evaluation (Robinson Jr (1972)).

4. System workflow design

Our proposed system for instructional planning of iVR-based learning units rests upon our foundational research on incorporating Backward design principles to effectively design learning curriculum for virtual welding training (McTighe and Thomas (2003); Wiggins and McTighe (1998); Ipsita et al. (2022)). In our prior work, by adopting the Backward design approaches, we identified the desired learning outcomes first by collaborating with SMEs in welding domain, subsequently worked "backwards" from the desired performance to identifying the assessment strategies, and finally designing the learning activities to meet the goal. The learning modules for the virtual welding simulator were then designed in a structured format to help users learn the concepts of safety, machine setup, maintenance, and welding. The learning modules thus designed were arranged in a progressive manner after studying the existing welding manuals (Althouse et al. (2004); of Welding Technology (2007)) and discussing with the welding SMEs. However, the learning content of the virtual welding simulator designed at the end left little room for flexibility in planning instructions based on desired training requirements. This laid the motivation for our current research which aims at providing SMEs with the ability to flexibly plan, modify, test and iterate their learning units or modules based on the requirements of the training process.

The process of instruction planning typically involves breaking down learning units or modules into segments of learning activities that revolve around relevant theories, concepts, or skills. In our workflow, the planning of a learning unit is based on the overarching standardized instructional framework, which entails establishing a instructional flow comprising of appropriate learning activities grouped under the four instructional phases of *Introduction*, *Presentation*, *Practice*, and *Application*. This instructional framework is common across various instructional design models and outlines the entire process of designing a learning experience, from audience analysis to implementation and revision (Yong et al. (2016); Kruse (2009); David Merrill (2002); Bybee et al. (2006)). Based on specific guidelines for planning and organizing instructional activities, the instruction framework revolves around the learning outcomes, and prioritizes learner assessment and feedback throughout the process; and therefore, can be easily integrated with the Backwards design framing of the curriculum (Yong et al. (2016)). We now briefly explain the four instructional phases utilized in the instruction planning process while providing examples of learning activities associated with each (Concordia University and Learning (2021)).

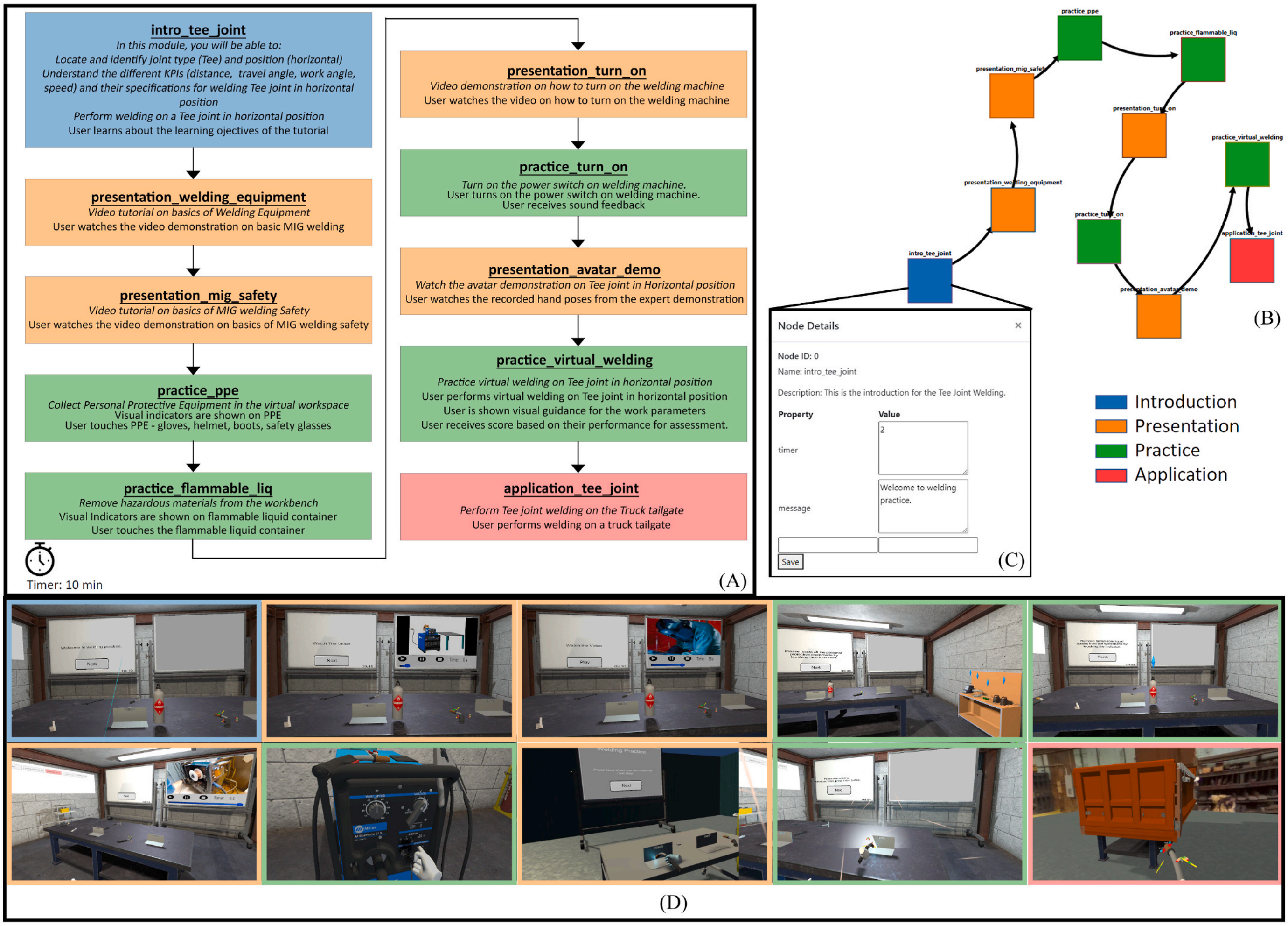


Fig. 2. An example implementation of the instructional planning of learning units using FlowTrainiVR: (A) Flowchart representation of the step by step planning of the learning unit, (B) Authoring the sequence of the iVR learning unit using the flow editor, (C) The dialog prompt showing the details and editable properties of the node, and (D) Verification and testing of the learning unit in VR.

- ***Introduction:*** This phase of instruction serves as the introduction to the topic. Some guiding principles which can be considered while designing learning activities for this phase are: (1) enable students to remember prior experiences they can build on, (2) set expectations by sharing learning outcomes, and (3) provide necessary hook to arouse emotions and feelings in learners to facilitate better learning and retention. Examples of learning activities can include stories, videos, readings, diagnostic quizzes, etc.
- ***Presentation:*** This phase of instruction is where the students engage with the content needed to achieve the learning objective. Some guiding principles which can be considered while designing learning activities for this phase are: (1) determine what content is need-to-know vs. nice-to-know for achieving the objectives, (2) involve learners in actively learning the content within the situated learning context, and (3) make the content accessible and immersive for the learners. Examples of learning activities can include guided video tutorials, avatar demonstrations, narrations, and readings.
- ***Practice:*** This phase of instruction is where students perform practice activities, targeting understanding of the specific content and performance of skills. Some guiding principles which can be considered while designing learning activities for this phase are: (1) model and scaffold skills using necessary cues and prompts, (2) provide support mechanisms in terms of cues, hints and prompts, and (3) associate built-in evaluation and feedback. Examples of learning activities can include quizzes, Q&A practice, and hands-on practical assignments.
- ***Application:*** In this stage of instruction, students are applying new content and skills to authentic situations and integrating this with previous knowledge. Some guiding principles which can be considered while designing learning activities for this phase are: (1) mimic real-world tasks in the field, (2) provide students opportunities to draw from their own diverse backgrounds and experiences, (3) associate built-in evaluation and feedback. Examples of learning activities can include application tasks specific to the discipline.

Therefore, the design of learning units involves selecting appropriate activities from each instructional phase, taking into account the necessary support and practice learners will need to grasp a particular concept and achieve the associated learning outcome. Each activity within the unit serves a specific purpose in assisting students in attaining the learning outcome. For instance, certain activities provide information on theories, definitions, or processes, while others concentrate on practice and application. Collectively, this collection of learning activities equips students with the necessary understanding, practice, and application of the relevant content.

4.1. Implementation

The system workflow design for planning iVR-based learning units comprises of three stages: (A) Developing a library of learning activities, (B) designing the instructional flow using a graph-based flow editor, and (C) testing and verifying the instruction sequence of the learning activities. An example implementation is shown in Fig. 2.

Developing a library of learning activities: The first step involves SMEs and VR developers working together to frame a set of learning activities by designing backwards from the overarching learning outcomes. Then, the development of the activities is performed by VR developers, while saving JSON configuration files for each. The configuration files contain the properties of the corresponding learning activities, that can be utilized by SMEs later to understand and/or edit the modifiable properties to personalize the training scenario. To test our approach, a library of 27 learning activities was developed for the welding use case, comprehensive enough to teach a class on basics of MIG welding including safety, welding equipment, welding wire change maintenance and Tee joint welding. The framing of the learning activities was based of our prior work where we collaborated with a team of SMEs, and by following the principles of Backward design from learning sciences came up with the learning activities that were sufficient to help learners gain the skills required to achieve the learning outcomes (Ipsita et al. (2022)).

Designing the instructional flow using a graph-based flow editor: To create the sequence of the learning activities catering to the needs of training, we developed a graph-based flow editor. The nodes of the graph represent the learning activities which can appear on the interface by clicking corresponding learning activities from the library. SMEs can bring as many nodes onto the interface that they want to include in their training scenarios. Directed edge connections can be created between the nodes to create the instructional flow of the learning units. The interface has a resource library tab that allows users to view the available resources in the four specific categories of Introduction, Presentation, Practice and Application. The *Controls* button is provided to show the detailed instructions on how to use the flow editor. There are *Upload*, *Delete* and *Download* buttons on the interface that allows the users to upload an existing scenario, delete the entire flow on the interface and download the scenario flow from the interface respectively. Users can individually delete any node or edge on the flow editor as well. There is a dialog box which appears on selecting a node and pressing key 'Y' which shows the node details including any editable properties for the node. Using the editable properties, users can personalize the learning activities based on the configurable parameters available for the corresponding activity. In the current version of the work, the configurable parameters are limited to: (1) *Timing:* This indicates the time duration to spend for the activity, (2) *Message:* This indicates a short description shown to the learner, e.g., the objective of the learning activity. (3) *Hint:* This indicates whether to show the audio and/or visual cues associated with the learning activity. The nodes are color-coded to help users distinguish between the node categories. Check prompts are also provided to check if any node in the graph contains more than one incoming or outgoing edges, or multiple sequences.

Testing and verifying the instruction sequence of the learning activities: Once the scenario flow is designed, SMEs can save the corresponding JSON file in designated file path. When the front end is started, the Unity application reads the JSON file from the path to dynamically generate buttons with the corresponding node names on the instruction screen. A Depth First Search (DFS) algorithm is utilized to generate the sequence for the learning activities to appear in the instruction screen in Unity. SMEs can either choose to view and verify the sequence in order. Or they can click on a specific button to jump to that particular activity. After verifying the sequence of the scenarios, users can go back and alter the flow till they are satisfied with the scenario design.

5. User study

5.1. Study setup

The study was conducted with 12 participants (1 female, 11 male) (Age Range (number of users) = 18–24 (4), 25–34 (8)) with prior welding experience who were recruited by word of mouth, email and flyer distribution. Eight users had prior experience with VR while the remaining four were novices in VR. Each user study was divided into three sessions where the task was to build three training scenarios, one per session. Each user was asked to plan the three scenarios in order, which were targeted towards gradually varying learning objectives. During this three-session study, the usability of the system workflow was evaluated while examining how users interacted with the different system components to plan and verify training scenarios for welding based on target requirements. The study was approved under the IRB protocols.

5.2. Study procedure

Users were first required to sign the consent forms and then proceeded to complete a short demographics survey. User demographics was collected about any prior experience with welding, VR, curriculum or instruction design, and teaching. Next, users were provided with the basic information in the form of a PDF text, a PowerPoint presentation and verbal instructions from a researcher explaining the overall theme of the study. The information included the objective of the study, a short description about the four instructional phases, and the available learning activities under each phase that the users could use to plan the training scenarios. The available resources were enumerated in a table with their names and a short description, the sequence of which was randomly chosen. The PowerPoint presentation was prepared containing visual description of the available iVR-based learning activities, in the form of images or videos. After going through the resources, users were informed about the task of creating three training scenarios in three different sessions in order, the requirements of which were gradually disclosed immediately before the corresponding session started. Users were asked to consult the researcher present in the scene in case of any questions during the study.

For the first session, users were first informed to imagine themselves to be the welding instructor of a class. The task was to plan a Tee joint Welding tutorial for a VR welding simulator to teach the imaginary class of students. Users were asked to come up with a tutorial title and the associated learning outcomes, and write them on a piece of paper. Instructions were then provided on how to use the flow editor and the resource library to design the training scenario. This followed with the users designing the tutorial using the relevant learning activities in the order that they deemed appropriate for their tutorial. After finishing up the tutorial, they were prompted to save the sequence to a specific path. Next, a researcher explained the controls of an OculusQuest™ to the user to be able to navigate between different learning activities in the VR tutorial. Users were then asked to verify and test the sequence that they designed using the flow editor in VR. After the users finished verifying their sequence in VR, they were given the choice to iterate on their original plan to incorporate any further modifications. When they were satisfied with the final tutorial design, they were asked to proceed to the second session.

During the second session, the users were informed about a change in requirements from the first session that the students in the imaginary class were novices in the field and did not have prior experience in welding. Considering this change in requirement, the new task was to build upon the previous tutorial plan to include additional information on basics of MIG welding, e.g., welding safety and equipment. The study procedure remained the same as before where users modified the previous tutorial plan based on the new information, and subsequently tested and verified the modified sequence.

Table 1
Session timings from the user study showing the averages and standard deviation of the time taken to complete each session (in minutes). The *Graph* column indicates the time required for planning the learning unit using the graph editor, whereas the *Unity* column indicates the time required to test and verify the instruction plan in VR.

Time (in minutes)	Session 1		Session 2		Session 3	
	Graph	Unity	Graph	Unity	Graph	Unity
Mean	14.47	11.53	3.66	4.93	3.09	6.07
Std Dev	7.31	3.90	1.43	2.61	1.47	5.16

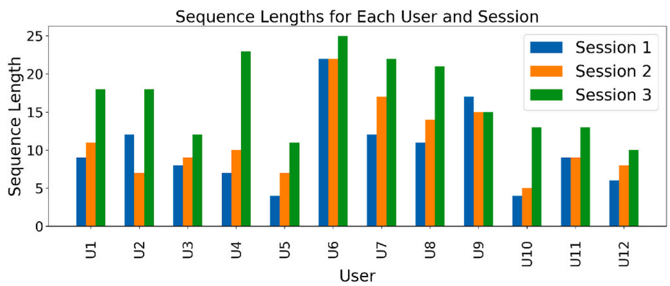


Fig. 3. Distribution of the sequence lengths for each user and across each session.

During the third session, the requirement changed again. It was realized that the students were needed to be taught about the welding wire change maintenance, and thus the tutorial had to be modified based on the updated requirements. Same as before, the users were asked to modify the tutorials, and verify and test the changes in VR. After the three sessions were finished, the users were asked to finish a survey questionnaire asking them to record their responses about their perception and experience with using the system. The study finished with a short conversational interview where users were asked about their experience with the system, comments on improvement, and potential of the system to be used for training purposes. The study lasted for approximately an hour and each user was given $15 compensation.

Data was collected for each user in terms of: (i) time required to finish each session task, (ii) JSON files for the training scenarios, (iii) 5-point Likert scale-based custom questionnaire to evaluate the usability, user perception and experience about using the system components, and (iv) conversational interview. Each user study session was recorded from a third-person camera view in the real environment. A researcher recorded the duration of the tasks in real time during the three sessions. The third person camera record was manually checked later, in case review was needed or a timing was missed. Data about the welding training scenarios was recorded from the flow editor for the three sessions. This data was analyzed later to obtain information about the ability of the system to enable flexible authoring of training scenarios based on variable learning objectives. After each task, users recorded their experience with the system using a 5-point Likert survey. The subjective comments and suggestions from the users during the conversational interview were audio-recorded and later used in the paper to explain the study results and inspire future design insights.

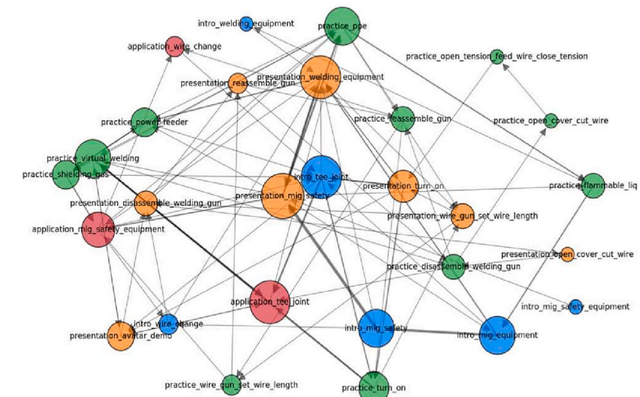
5.3. Results

Time required to finish each session tasks: The average time duration of the different tasks, i.e. (1) the planning of the learning unit using the graph editor and (2) testing and verifying the instruction plan in VR during the three sessions are shown in Table 1. Session 1 required the most time for both planning the instructional sequence using the graph-based editor and testing the sequence in Unity. The longer duration was due to users needing time to familiarize themselves with the system's features when the study started. The reduced times for Sessions 2 and 3 indicate that users quickly adapted to the system. In Session 3, the testing time in Unity was higher than in Session 2 due to increased target requirements leading to longer instructional sequences with more learning activities.

JSON files for the training scenarios: The JSON files from the training scenarios were analyzed to check for similarities, variations and patterns in sequence distributions across the different sessions and for different users. The sequence lengths of the training scenarios for different users in the three sessions are shown in Fig. 3. The sequence lengths increased across sessions, with Session 2 having longer sequences than Session 1 for 75% of users, Session 3 having longer sequences than Session 2 for 91.6% of users, and Session 3 having longer sequences than Session 1 for 91.6% of users. This trend reflects the progressively increasing learning requirements of the instructional units. For example, in Session 2, users were asked to modify the Tee joint welding unit from Session 1 for novice welders by including materials on welding basics and safety, leading them to add necessary activities to meet the target objectives. Similarly, in Session 3, when the requirements included learning about welding wire changes, users added the necessary activities, resulting in longer sequences. After checking that the assumptions of normality (Shapiro-Wilk test, $p > 0.05$) and homogeneity of variances (Bartlett's test, $p > 0.05$) are met in the data, the one-way ANOVA test across sessions was performed to identify any significant variations in sequence lengths across sessions. The ANOVA results ($p^* = 0.0065$) indicated statistically significant differences in sequence lengths across the sessions. To conduct further post-hoc tests to determine which specific sessions differ significantly from each other, Tukey's Honestly Significant Difference (HSD) test was performed. Statistically significant differences were observed between Session 2 and Session 3 ($p^* = 0.03$), and Session 1 and Session 3 ($p^* = 0.0084$) in terms of sequence lengths. There was no statistically significant difference between Session 1 and Session 2 in terms of sequence lengths ($p = 0.8517$).

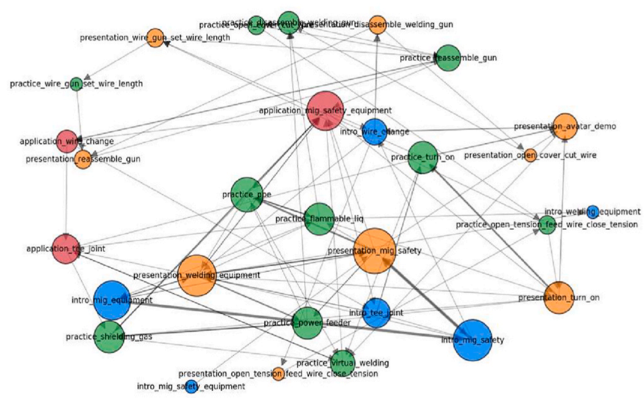
The frequency of occurrence of each item in the sequence were analyzed to identify commonly recurring items and their patterns. The node-link diagram for the graph sequences from the three-session user study is provided in Fig. 4 to aid in visual understanding of the analysis. In the node-link diagrams, the circular nodes represent the nodes or the learning activities in the instruction sequence, with the nodes radii indicative of the frequencies of their occurrences. The links represent the connections between the learning activities in the instruction sequences, with their direction and thickness indicative of the order and frequency of their occurrences respectively. As can be seen, Session 3 features larger nodes with darker edges compared to previous sessions. The progressively larger nodes and thicker edges in the figure across the three sessions indicate increasing frequencies of the learning activities. This trend reflects the growing requirements presented to users in each session, leading to more nodes and connections being added to the instructional sequences. The figure also shows the tabular representations of the most commonly occurring nodes and edges in the graph sequences along with the frequencies of occurrences from the three sessions. It is worth noting that the frequently occurring nodes and edges in each session are directly associated with the changing requirements. For example, in Session 3, the nodes *intro_wire_change* and *practice_turn_on* each appeared 10 times, reflecting the new requirement to modify the learning sequence to include details about welding wire change. Additionally, the grouping of activities under the four instructional phases—*Introduction*, *Presentation*, *Practice*, and *Application*—encouraged users to follow a logical sequence. This pattern is evident in Session 2, where *intro_mig_safety* is frequently followed by *presentation_mig_safety*, and in Session 3, where *presentation_turn_on* is often followed by *practice_turn_on*. The intuitive nature of this structure made it easier for users to create coherent instructional sequences.

5-point Likert scale-based survey questionnaire: The custom questionnaire results were analyzed to evaluate the usability, user perception



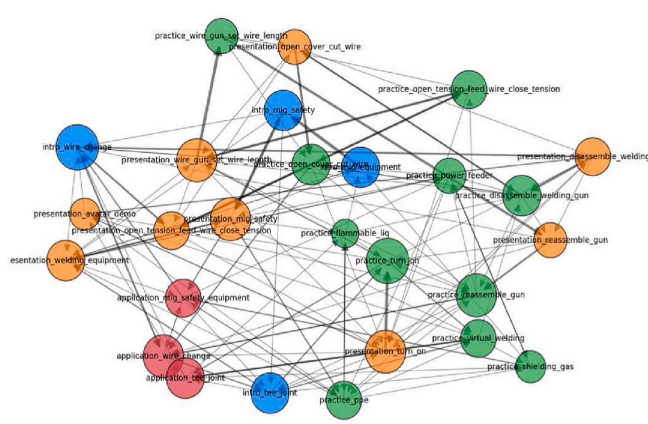
Nodes	Edges
presentation_mig_safety, 10	('intro_mig_safety', 'presentation_mig_safety'), 5
presentation_welding_equipment, 9	('presentation_welding_equipment', 'presentation_mig_safety'), 4
intro_tee_joint, 9	('intro_mig_equipment', 'intro_mig_safety'), 4
application_tee_joint, 9	('intro_tee_joint', 'application_tee_joint'), 3
intro_mig_safety, 7	('practice_turn_on', 'practice_virtual_welding'), 3

(A) Session 1



Nodes	Edges
presentation_mig_safety, 12	('intro_mig_safety', 'presentation_mig_safety'), 7
intro_mig_safety, 10	('intro_mig_equipment', 'intro_mig_safety'), 6
presentation_welding_equipment, 10	('presentation_turn_on', 'practice_turn_on'), 4
intro_mig_equipment, 9	('presentation_mig_safety', 'practice_ppe'), 4
application_mig_safety_equipment, 9	('presentation_welding_equipment', 'practice_power_feeder'), 3

(B) Session 2



Nodes	Edges
intro_wire_change, 10	('intro_mig_equipment', 'intro_mig_safety'), 5
practice_turn_on, 10	('intro_mig_safety', 'presentation_mig_safety'), 5
presentation_mig_safety, 9	('presentation_wire_gun_set_wire_length', 'practice_wire_gun_set_wire_length'), 5
presentation_wire_gun_set_wire_length, 9	('presentation_turn_on', 'practice_turn_on'), 5
presentation_turn_on, 9	('presentation_open_tension_feed_wire_close_tension', 'practice_open_tension_feed_wire_close_tension'), 4

(C) Session 3

Fig. 4. Node link diagram for visualization of the graph sequences from the three-session user study alongwith the commonly recurring nodes and edges in the graph sequence.

and experience about individual components of the system during the individual steps of the planning process. All Likert scale questions from the custom questionnaire survey are reported with mean (M) and standard deviation (SD) in Table 2. Users perceived the individual components to be useful in the tutorial planning process (Q1). The components accurately captured and reflected their intent during the tutorial planning (Q14, Q15). Users could modify and iterate the tutorial based on changing requirements (Q3, Q5, Q7). The editable properties also helped to personalize the content based on requirements (Q2). The users reported high scores towards the system being easy to use and getting familiar with the system components easily (Q12, Q13, Q16, Q17). The tutorial experience in VR was enjoyable (Q6, Q9). The resources felt sufficient to plan the tutorials (Q18, Q8). They perceived the usage of such systems to be helpful in planning tutorials in educational setting (Q10, Q11).

6. Discussion

Based on the user study results and the subjective feedback from the users, we try to answer the research question that was posed before. ***To what extent do the system components enable SMEs to flexibly author training scenarios based on varied learning objectives?***

The positive ratings received from the survey results indicate that the different components of the system helped users in planning the learning

Table 2
Survey Results from User Study (5-point Likert Scale rating where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree).

Survey Questionnaire	Mean	SD
Q1: The system helped in planning the tutorials for the welding simulator.	4.25	0.43
Q2: The editable properties of the nodes were useful to personalize your tutorial content during the tutorial planning process.	4.00	1.08
Q3: You could modify the tutorials as per the changing requirements.	4.33	0.62
Q4: It required a lot of preparation to get familiar with the planning process.	3.00	1.08
Q5: You were able to test and verify the tutorial you planned using the system.	4.17	0.55
Q6: The tutorial experience in VR was enjoyable.	4.58	0.49
Q7: You could iterate upon the existing plan to make desired changes.	4.33	0.75
Q8: The system was sufficient to plan the tutorials as per the requirements.	4.33	0.62
Q9: The Virtual Reality tutorial is engaging.	4.17	0.55
Q10: Such approaches can be useful to create VR lessons for training purposes.	4.42	0.64
Q11: Instructors can use such approaches to create VR lessons for their classes.	4.42	0.49
Q12: The web editor was simple to use.	4.25	0.60
Q13: You could get familiar with the web editor easily.	4.50	0.50
Q14: The VR content accurately reflected your intent in the tutorial plan made using the Web editor.	4.08	0.49
Q15: The interface of the web editor was successful in capturing your intent for the flow of the tutorial.	3.75	0.72
Q16: It was easy to choose resources from the library to add the learning activities of your choice.	4.25	0.60
Q17: It was easy to build connections to define the sequence of activities using the web editor.	4.08	0.64
Q18: The resources felt sufficient to plan the content for the welding tutorial.	4.33	0.47

units based on varying learning objectives. As the requirements of the training progressively increased, the users could add more learning activities gradually and build appropriate connections to cater to the changing needs. U8 pointed out, *"The flow editor was pretty good, you could build really complex systems from simple formats or modules that already existed and change model based on individual preference because some people come with some background and some people lack some background. So you can actually customize it based on individual, that was a really good part about it."* This is further evident from the sequence distribution analysis, where an increasing trend of sequence length was observed across most users throughout the study as the sessions progressed as shown in Fig. 3. Users also found the learning activities were enough to build the training scenarios (Q18, Q8). As pointed out by U9, *"I did find the resources were enough and I was able to get through it."* It is crucial for VR developers to create a comprehensive set of learning activities to enable SMEs to author instructional sequences aligned with desired goals. Additionally, establishing a collective online library would facilitate seamless collaboration between VR developers and SMEs, allowing them to exchange ideas and resources for classroom use, and can be considered as a scope of future work.

As indicated from the survey ratings (Q12, Q13, Q16, Q17), the easy-to-use features of the system components helped users to get accustomed to the planning process. The graph-based flow editor simplifies the creation of instructional flows through intuitive clicks and drag-and-drop interactions. Users can add nodes with single clicks from the activity library and create edges by dragging and dropping. Once sequences are authored, they can be easily tested in Unity by wearing the HMD and selecting activities. This user-friendly interface is crucial, given the limited VR development expertise of SMEs, making it accessible for them to author iVR sequences effectively. About getting familiar with the flow editor, one user pointed out, *"What I felt is the whole system was pretty easy to use, except the part that when you link the nodes was kind of kind of cumbersome for a person new to this. But apart from that, once you get that right, the whole sequence is pretty easy. Even the presentations and the applications was pretty straightforward in VR."* This is further evident from the decreasing trend in the session timings from the user study as shown in Table 1.

The categorization of the learning activities as per the instructional framework made the planning process intuitive for the experienced welders. When asked about how did they come up with the sequence, U1 pointed out, *"So I try to do it chronologically or coherent way. If I want to learn this, then I should know about this. Then I should go there and I should do after this. Present it to them, then practice and then talk about application and like that"*. The editor could be useful to scaffold the instructions based on the target requirements. As pointed out by U3, *"Because I was able to organize my thoughts better when having different blocks and how they're connected together"*. An interesting observation from the JSON analysis that could be provided here is related to the significant differences in the sequence lengths between session 3 and the other two sessions. Session 3 which added the extra requirement of the welding wire change involved comparatively greater number of learning activities as compared to the other two sessions, which was easily perceived and interpreted by the users to plan the learning unit. Furthermore, the commonly recurring nodes and edges in the instructional sequence as shown in Fig. 4 also validates the efficiency and intuitiveness of the flow editor to plan learning units based on the desired learning objectives. Therefore, it is essential to align the design of authoring platforms for learning environments with established learning frameworks and theories to ensure better adoption and effectiveness within the learning community.

The ability of the system to verify and test the planned scenarios in VR helped users to make necessary adjustments to the planned unit in case they needed any changes. About the iteration of the scenarios, U10 pointed out, *"I didn't honestly understand the purpose of that particular session. So after I went into the VR and saw what was going on, I came back and decided to rearrange, so that, that will suit the lecture that I was going to explain in that particular session."* Furthermore, the ability to test content firsthand during the authoring process allows SMEs to see exactly what learners will experience (WYSIWYG). This capability enables them to quickly and accurately test and verify instructional sequences, ensuring confidence in the quality and effectiveness of the content for learners.

The users believed that such systems can find good use in the educational settings to adapt the training curricula based on training needs. As pointed out by U6, *"If you want to modify something, say if you want to change the sequence, you can do it by a click of a finger, like you can just change in the editor and make the change. So it gives a whole lot of flexibility for the teacher or the professor to modify the curricula according to the process."* The user also mentioned, *"And adaptation of the nodes depending on the applications, like depending on different sections is pretty straightforward."* When asked about where such systems can be used, U4 pointed out, *"I think it would be useful for its intended purpose which would be like maybe reshuffling components for lessons, then you can reorganize them as you need to, for students as needed. And maybe even like a live fashion, if you realize that their skill levels are not what you were prepared for."*

7. Limitations and future work

Design of the User Interface of the flow editor: Based on the subjective feedback from the user study, further research is required to design a suitable interface and interaction capabilities. Although we provided the users with the flexibility of making the nodes and edges move on the interface, this functionality was critically received by some users. As U3 pointed out *"For the web interface, maybe the things that are created first can go up on the screen and slowly cascade downward rather than make a circle and sort of move around a good point."* Another user U4 also mentioned that the choice of the interface could be a timeline instead of a graph-based editor, *"Since the lesson is linear, it can be a timeline where you can like drag and drop things out of the timeline."*

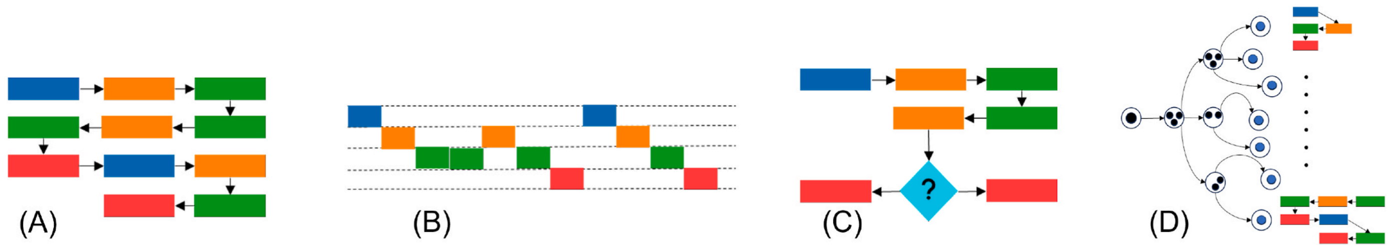


Fig. 5. Various possibilities of flow editor designs and scope for enhancement of features and functionalities.

Considering these comments from the users, another study could be conducted with users while taking the viewpoint of user experience interaction designers to outline the design guidelines for laying out the specifications for the instruction planning interfaces. A few possible designs are shown in Fig. 5 A, B based on the comments from users.

Functionalities of the flow editor: In the current set-up, the nodes that are grouped under the four instructional phases of Introduction, Presentation, Practice and Application, have evaluation and feedback embedded into the individual learning activities. The functionalities of the flow editor can be extended to include decision based rules and nodes to author properties for evaluation and feedback in the scenario flow. An example of this is shown in Fig. 5 C.

Furthermore, node clusters and collapsible node structures can be used to contain sub-sequences and create hierarchies of content rather than displaying everything on the same screen. This feature can be extended to design the course curriculum and accompanying chapters and lessons. The visual representation of this idea is shown in Fig. 5 D.

Level of Detail: The editable properties of individual nodes in the flow editor are limited to the configurations saved by the VR developers for the corresponding learning activities. The assumption of meeting requirements for personalization in this process is based on the effective collaboration between SMEs and VR developers to define these properties. However, if the authoring is supposed to be performed at finer level of details for the individual learning activities, e.g., requiring dynamic manipulation of the 3D content, further research is required (Hayatpur et al. (2019)). This is however outside the scope of the current work.

Recommendation of nodes: AI-based recommender systems can be used to provide context-specific suggestions to instructors about nodes and sub-sequences relevant to the context, instead of having them to choose individual nodes from the library. This can further enhance the usability of the planning process.

Functionalities of the VR interface: The continuity of flow within the instructional sequence is crucial to keep the users immersed in the virtual environment. It is required that the VR developers should pay close attention during developing the learning activities to enable smooth transition between the activities in VR. Therefore, future research can provide guidelines to ensure rich user experiences in the customized learning units.

Development of Learning outcomes: The FlowTrainiVR system offers valuable technical insights into developing an iVR-based learning planning system, but several areas require further attention. Firstly, the evaluation currently focuses only on SMEs. Including feedback from learners would provide a more comprehensive assessment of the system's effectiveness, as it is designed for outcome-oriented learning. For future work, we recommend examining the impact of the proposed design methods on learners' development of learning outcomes. Deploying the learning units in a classroom setting will require additional evaluation requirements, which should be addressed in future studies. Previous research has shown that outcome-oriented learning, with objectives aligned to target outcomes, has significant advantages in achieving faster and more targeted learning outcomes. We believe that the flexible authoring of learning units can foster the desired skills by tailoring the learning content to the desired learning experience. While testing with trainers indicates positive results regarding the flexible development of learning units, further analysis is needed to evaluate the design methods' impact on learning outcomes.

Currently, the alignment of learning theories with the development of iVR learning content is limited, preventing a comparative study in this area. Nonetheless, we hope our work provides insights for future research to explore this area in greater depth.

8. Conclusion

We presented FlowTrainiVR, a system workflow design that facilitates collaboration between subject matter experts and VR developers towards planning of iVR-based learning units based on the training requirements. The workflow begins with VR developers developing a library of learning activities with configurable parameters, based on the learning outcomes and assessment identified using the Backward design approach. These learning activities are grouped under the four instructional phases of Introduction, Presentation, Practice and Application, based on the scalable instructional framework for instruction design. Using the learning activities as the building blocks, subject matter experts can plan their learning units using a graph-based flow editor. These units can be later verified in VR to test their effectiveness in meeting desired learning objectives. Using a welding use case, our user study with 12 experienced welders showed the effectiveness of the system to author flexible training scenarios based on varied learning objectives. The positive ratings from the users indicated usability of such workflows in designing iVR-based learning units. We believe that the insights obtained from the research can be helpful towards enhancing the adoption of the immersive technology in educational settings.

Statements on open data and ethics

The participants were protected by hiding their personal information in this study. They were voluntary and they knew that they could withdraw from the experiment at any time. The data can be provided upon requests by sending e-mails to the corresponding author.

CRediT authorship contribution statement

Ananya Ipsita: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mayank Patel:** Visualization, Software, Resources, Methodology, Data curation. **Asim Unmesh:** Software, Methodology, Formal analysis. **Karthik Ramani:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cexr.2024.100074.

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