Educator Perceptions of XRAuthor: An Accessible Tool for Authoring Learning Content with Different Immersion Levels

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Abstract

The promise of Extended Reality (XR) in education is significant but one size does not fit all learning contexts and student preferences. Varied content with different immersion levels is hence beneficial, but creating XR content remains daunting for educators using conventional tools. This paper introduces XRAuthor, a web-based authoring tool designed to empower educators to create varying immersive learning content - ranging from conventional video to interactive animations and full-fledged VR - all from a single authoring experience with a webcam. Through online one-to-one workshops with 14 educators, we found strong endorsement for the new authoring workflow enabled by XRAuthor. Participants also found that the varied interactive exercises automatically generated by the tool aligned well with effective pedagogical practices. High ease of use and efficiency were identified as crucial attributes of XRAuthor. The design knowledge facilitated by XRAuthor underscores the potential of such tool designs to democratize XR content creation for learning.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**; **User interface design**; *Web-based interaction.*

Keywords

virtual reality, augmented reality, learning tools, self-driven learning

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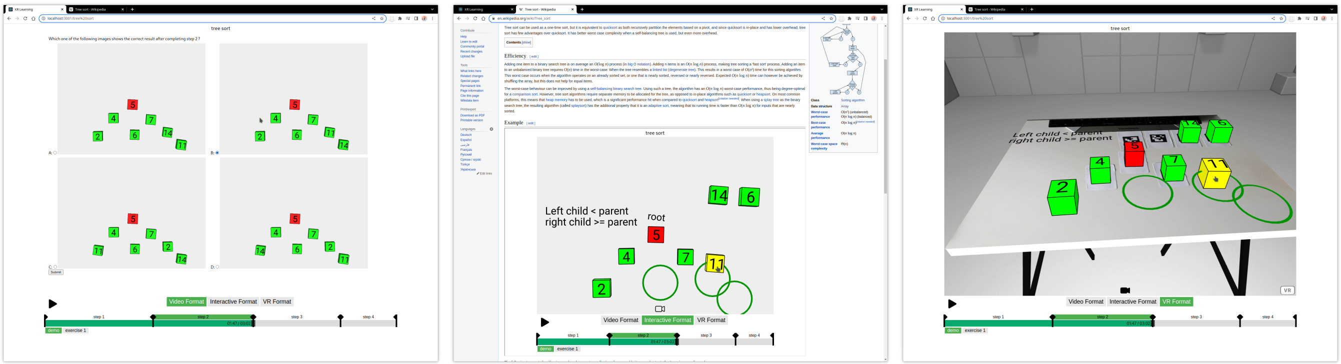
1 Introduction

In the fast evolving education landscape, Extended Reality (XR) technologies like Virtual Reality (VR) and Augmented Reality (AR) have shown great potential in enhancing educational experiences [18, 25, 26]. For instance, VR simulations can help biopharmaceutical engineering students integrate theory and practice more effectively [8], and AR can engage physics students with animated digital overlays on physical artifacts [30].

While the potential benefits of XR in education are evident, the practical implementation of XR content creation remains a significant challenge for educators [1, 21]. This challenge is further compounded when educators must develop diverse XR content across varying levels of immersion to accommodate learners' differing preferences, access to XR devices, learning contexts, and prior knowledge, among other factors. Ensuring that XR content meets these varied needs is critical for achieve desired learning experiences and outcomes [3, 17, 32–34]. However, existing tools often require specialized technical skills and are not specifically designed to support educators in creating XR content at different immersion levels.

To address this gap, this paper aims to initiate design knowledge for developing accessible tools that empower educators to seamlessly integrate XR into their teaching practices. To this end, we developed XRAuthor, a web-based authoring tool that empowers educators to easily transform their video content into different levels of immersion for integration into their teaching practices. We then conducted workshops with XRAuthor involving 14 educators to investigate the following research question:

RQ How can we design an authoring tool for educators to effectively create learning content, derived from physical learning activities, to be delivered across multiple immersion levels (video, interactive and VR)?



(a) (b) (c)

Figure 1: An example lesson on tree sort in three formats. Video Format (a): a participant answering a multiple-choice question in a standalone web app, Interactive Format (b): a participant interacting with cubes to complete a step of the learning content embedded in the Wikipedia page of tree sort, and VR Format (c): a participant completing a spatial task in the VR preview mode.

2 Related Work

Despite XR's benefits, current literature underscores the importance of diverse content formats. The effectiveness of XR is highly dependent on learning contexts, learners' prior knowledge, and access to requisite hardware and software. Shen et al. [33] examined training effects across different immersion levels, highlighting the influence of participants' existing domain knowledge and prior VR experiences on their perceived usefulness of various virtual learning environments and their training media preferences. Funk et al. [13] observed that AR only benefited untrained workers in an industrial assembly workplace, and Sowndararajan et al. [34] reported better outcomes with higher immersion only for the task of memorizing complex procedures. Additionally, the complexity of tasks and their visual representations have been shown to significantly influence the impact of immersive environments on learning [3, 17, 32].

The practical feasibility of creating XR learning content also remains a complex and multifaceted challenge. Educators may lack technical skills in creating XR content; for instance, conventional tools demand proficiency in programming, using game engines such as Unity or Unreal, or AR/VR toolkits like Google ARCore or Apple ARKit. This gap between potential benefits and the practical implementation of XR in education is evident [1, 21]. Several early works have explored experimental XR authoring tools, mainly focusing on predefined tasks or in non-education contexts. For example, ProtoAR [20], CAVE-AR [6], ScalAR [28] and Corsican Twin [27] help designers create AR experiences using mobile phones or through VR environments. XRDirector [19], Authoring-by-Doing [38] and ProcessAR [9] generate AR/VR scenes based on designers' or experts' actions in virtual environments. FlowMatic [40], GesturAR [36], PhyOOP [37] and EntangleVR [7] provide visual programming interfaces in VR/AR environments or the Unity editor for creating immersive content, while GVT (Generic Virtual Training) [15] supports programmatically creating procedural tasks in VR. Meta-AR-App [35] facilitates collaborative learning in STEM classrooms while Paper Trail [31] integrates virtual content with physical pages. Other than usability shortcomings for these experimental tools, they often focus on a single immersive learning format, failing to cater to the needs of diverse learners.

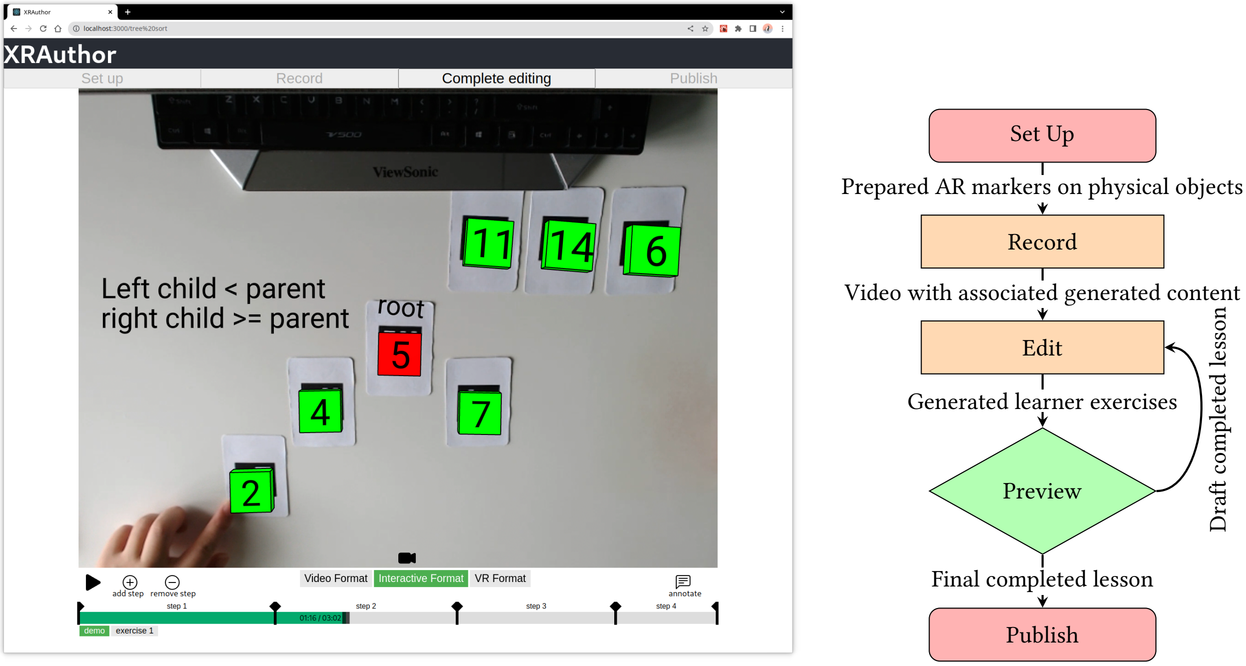
Learners exhibit varying levels of familiarity and comfort with immersive experiences, necessitating XR content in multiple formats tailored to distinct immersion levels. However, creating such XR learning content remains a significant challenge, highlighting the need for accessible tools designed specifically for educators. XRAuthor's novel workflow streamlines the production of learning content with multiple immersion levels through a single process using a webcam (Section 3). Using think-aloud and interview data from one-to-one workshops with 14 educators, we performed thematic analysis (Section 4) to generate the themes (Section 5). We then discuss their implications for the educator tool designs (Section 6) and conclude with limitations and future work (Section 7).

3 XRAuthor

Motivated by the need for a educator-friendly authoring process while delivering diverse immersive learning content, XRAuthor was created as an open-source initiative (https://github.com/singaporetech/immersification-xrauthor). Designed for accessibility, it operates directly in a web browser, eliminating the need for installation (refer to Appendix A for its implementation details).

XRAuthor simplifies the authoring workflow by leveraging the common practice of using a webcam for video lessons, a method widely adopted by educators [23]. From these recorded videos, the tool automatically generates interactive learning content in three distinct formats (Figure 1) tailored to different immersion levels, that vary in their visual fidelity and freedom to interact with the virtual environments [11, 33]:

- **Video Format**: Augments traditional video lessons with virtual objects and incorporates multiple-choice questions (MCQs) for easy learner interaction on desktop or mobile devices.
- **Interactive Format**: Generates animated virtual objects from the video, introducing tasks that require richer screen-based movement interactions on desktop or mobile devices.



(a) (b)

Figure 2: XRAuthor's authoring UI and process. A view (a) showing the "Edit" step on a sample recording of a data structures lesson on binary trees, and the process (b) from the physical teaching environment *Set Up* to *Publish*ing on the web.

- **VR Format**: Creates a full-fledged VR environment (e.g., a virtual classroom) from the video, featuring spatial tasks that demand natural motion-tracked controller gestures for learner interaction on XR HMDs.

XRAuthor's authoring workflow (Figure 2b) starts with a **Set Up** step, where it guides educators to configure the virtual objects attached to physical markers, including text labels, colors, and 3D models. Then they click "**Record**" to initiate a video capture of themselves demonstrating the learning content in front of a webcam, while the positions of the AR markers are tracked and recorded. They can then click "**Edit**" (Figure 2a) to review the recorded video and segment the content into steps, prompting the tool to generate interactive tasks and questions based on recorded positions (across the "Video Format", "Interactive Format" and "VR Format"). Finally, they click "**Publish**" to upload the content, making it accessible online for learners to access in their preferred format, e.g., as a standalone web app or embedded into existing sites like Wikipedia (Figure 1b). (Note that detailed instructions are documented in the GitHub repository: https://github.com/singaporetech/immersification-xrauthor.)

It is not uncommon to see tutorial videos to use cards or physical objects to explain concepts. The tool extracts the sequential and spatial information from these videos to generate interactive activities. Learners can perform same actions they see in videos, such as moving virtual objects to complete tasks or answering questions of correct positions of virtual objects, to enhance their understanding of the concepts. The prototype is not designed for a specific domain, instead, to provide an accessible and easy-to-use tool for educators to make full use of their existing video recording practices to create interactive learning content across various formats.

4 Method

We conducted one-to-one online workshops using Zoom to gather user perceptions and insights into XRAuthor, addressing the RQ in this paper (Section 1). Data collection involved semi-structured interviews and think-aloud vocalizations during their interactions with the tool. Given the challenges and risks associated with conducting face-to-face experiments due to COVID-19, we opted for a remote approach using the video conferencing tool Zoom. This decision was based on the tool's online accessibility and the capacity to capture most user interactions through screen sharing and webcams.

We chose an example topic of sorting algorithms to evaluate user experience, as it is a good representation of learning activities that involve abstract concept comprehension and spatial interactions, which aligns well with the spatial affordances of XR.

4.1 Participants

Participants consisted of educators with teaching experience in computing disciplines, as the sample lesson was on sorting algorithms. They were recruited through university mailing lists of relevant faculties in Singapore and Australia.

We completed workshops with 14 participants, aged 27 to 55 (M = 39.6, SD = 7.26; 3 females), of whom 10 had more than 3 years of teaching experience (M = 5.83, SD = 6.27, range = 0.42 to 25 years).

Table 1: Code Frequencies

	Theme	Code	Frequency
1	Multiple Formats Cater to Different Learner Profiles	multiple formats are useful	9
		modality usefulness depends on the topics and/or learners	7
2	High Ease of Use to Record and Edit Content	easy to follow	12
		some areas needed additional guidance	6
		intuitive and straightforward, despite having fewer VR Preview and Timeline features	6
3	High Perceived Efficiency to Generate Multiple Formats	creating multi-format learning content is easy and efficient	9
		concerned about recording preparation effort	2
4	Interactivity Enhances Learner Experiences	see broad value of interactivity for learners	12
5	Limited Learning Scenarios Due to Interaction Implementation	useful for step- and puzzle-based learning scenarios	13
		application needs to be extended	8

For teaching, 11 had no prior experience with XR content, while all 14 frequently used video recordings. 9 had experience with other forms of XR.

4.2 Procedure

The workshop comprised three phases: demonstration, try-out, and interview, spanning 60-90 minutes per participant (the study was approved under the authors' university's Institutional Review Board, ID: ETH22-7540).

Demonstration: A conductor demonstrated tool functionalities. Participants were provided with insights into how to author content with the tool and effectively utilize the generated learning materials. The demonstration aimed for participants to possess a comprehensive understanding of the tool's authoring workflow (Figure 2b). Participants were actively encouraged to pose questions for clarity, ensuring the accomplishment of the demonstration's objectives.

Try-out: Participants accessed XRAuthor through a web URL to interact with it based on several provided objectives (a brief version is summarized in Appendix B). Participants shared their screens over Zoom and were prompted to think-aloud their thoughts while interacting with XRAuthor until satisfied with their familiarity with the tool.

Interview: A semi-structured interview was conducted with participants to capture any experiential insights not articulated during their think-aloud vocalizations (a selection of initial questions are detailed in Appendix C).

4.3 Data Collection, Preparation and Analysis

The transcriptions were generated using OpenAI's Whisper [24], a contemporary speech-to-text tool, and then meticulously reviewed and cross-referenced with the original videos for accuracy by the first author. The subsequent thematic analysis employed an inductive method [5], facilitated by QualCoder [29], a qualitative data analysis tool, for maintaining a codebook to establish the mapping of codes to transcript excerpts. The second author reviewed the codes and participated in periodic meetings to discuss, align and refine the codes.

The coding process comprised three phases: (a) 61 low-level codes emerged from the textual corpus, (b) condensed into 10 high-level codes, (c) resulting in 5 themes (Table 1). For example the theme *Multiple Formats Cater to Different Learner Profiles* (Section 5.1) was derived from the high-level codes "multiple formats are useful" and "modality usefulness depends on the topics and/or learners" (Table 1), which, in turn, were derived from 7 and 5 low-level codes respectively.

5 Results

The results from the thematic analysis are organized into the five themes that emerged from the data. To substantiate the observations, the following subsections (themes) refer to the code frequencies in Table 1.

5.1 Multiple Formats Cater to Different Learner Profiles

Participants underscore the importance of offering multiple formats of learning content within XRAuthor to cater to diverse learner profiles.

Many participants found that "multiple formats are useful" (9/14), with VR praised for elucidating complex topics: "For example, if you're trying to explain how two 3D arrays might work or something, [...] (like having) a 3D model of the compound you're looking at would be more useful than just the 2D" (P7)

In addition to VR, participants emphasized the role of multiple learning modalities in making learning varied and fun: "There are different forms of interaction that the user can do, so the user, the student might be bored with just doing the MCQ, and they can do, choose the interactive format or VR format and kind of play around with it. It can make learning fun, right, so that way, learning might be more impactful." (P4)

Some emphasized the importance of multiple formats in making content more accessible to broader audiences: "So maybe I will use the interactive format to ask them to try individually because I think that is enough if they use a web browser. [...] I mean, as an instructor, I may not be able to expect them to have a VR headset." (P3)

A significant number of participants also acknowledged how the "modality usefulness depends on the topics and/or learners" (7/14), suggesting the importance of context for the different learning formats generated.

Some participants highlighted the contextual application of VR, stating its necessity depends on the topic's nature: "Yeah, there needs to be a motivation to do a VR. Yeah, if it's really 2D, then doing it in VR is probably an overkill." (P13)

Furthermore, the suitability of a modality not only hinges on the content but also on the learners involved: "Yeah, some students, they may don't like teacher asking me questions, and I don't know, maybe I will make a fool of myself or something, so some of them, they don't want teacher to make them more interactive.' (P6)

While diverse formats are beneficial, caution was expressed against excessiveness, which could potentially confuse learners: "The more you have, the more they confuse them, I think. Yeah, I think this is, keep it simple and easy, [...] If you over-complicate your system, you're making your work harder, and you make, you confuse your user as well." (P6)

5.2 High Ease of Use to Record and Edit Content

Although evaluating usability was not a focus, a majority found the overall process to be "easy to follow" (12/14).

Participants noted that XRAuthor was accessible to educators who are exposed to basic content creation tools: "I think if you're familiar with like video editing software and stuff, which I think most educators are at this point, um, then it's just a good, like a natural extension of that, right. It looks familiar." (P8)

Accessibility was often highlighted, e.g., interfacing with existing web environments: "This is all web-based and it's so accessible and it's easy to use. I can see it's integrating with any learning management system, Canvas, Blackboard, Moodle." (P12)

However, some participants mentioned that while the tool was intuitive, "some areas needed additional guidance" (6/14), especially for newcomers: "Yeah, because your current GUI is quite simple. There are not much explanation on it. Then it may take some time to learn." (P14)

Others appreciated the intuitive nature of the recording process, particularly with AR: "Yeah, moving the objects around is intuitive. I mean, more intuitive than using the PowerPoint, put the box and then drag here and then set the animation." (P1)

Questions arose about the essentiality of AR for recording, with some proposing its usefulness could vary based on topics and user preferences: "If we can virtually manipulate rather than physically manipulate that, that would mean that I can do it anywhere. But here for physical manipulation, I need to find space, I need to find markers." (P13)

Participants found editing to be "intuitive and straightforward, despite having fewer VR Preview and Timeline features" (6/14). For example, they found it easy to add steps and annotate content throughout the three formats: "Yeah, click anywhere and add a new step. So that was pretty intuitive. [...] The steps, yeah, adding the steps, that was nicely designed, it was pretty obvious how to do them." (P9)

However, some encountered issues with VR preview, mainly those who had more experience with existing tools and had preconceived notions: "So this is a standard tendency for music editing and for video editing kinds of tools with a certain timeline and all that and I was kind of like using those like for Adobe Premiere or those kinds of like Ableton." (P10)

5.3 High Perceived Efficiency to Generate Multiple Formats

For efficiency, many participants commended that "creating multi-format learning content is easy and efficient" (9/14).

An example was how the auto-generation of learner exercises saved time: "So what I like the most is the way that auto generates the exercises. I think that's incredibly helpful. Yeah, just again saves the educator so much time." (P9)

Participants also highlighted the efficiency of VR content creation, particularly appreciating that it required no coding: "(A PhD student) she actually got someone to build a bit of a interactive movie on Unity, and we had to get a student to develop this game prototype for her. And it took six months. So with this stuff, [...] I'll probably say it takes a couple hours as opposed to six months of development." (P12)

Participants also described XRAuthor role as a way to streamline multi-content creation: "just having to create one video and you can then have that explored and, you know, different, uh, modalities or without having to create multiple videos." (P11)

Despite commending on the efficiency, a small number of participants were "concerned about recording preparation effort" (2/14). "Just recording normal content, just writing on a pad and just recording that also is like, it takes a little more of a fine-tuning, even after the basic recording, so the only thing that, because I haven't done it, is that how much effort it is to record the (video), with the markers and everything." (P4)

5.4 Interactivity Enhances Learner Experiences

The majority of participants "see broad value of interactivity for learners" (12/14) , pointing out how XRAuthor's automatically generated learner exercises provide versatile benefits across various experiential dimensions.

Participants recognized the utility of interactivity in making learning engaging and enabling practice to understand concepts: "I'd probably say being able to create exercises based on your recording. Okay. Because if you explain the concept, but then you want your students to practice it, having the exercise mode, it's useful." (P12)

They found that the automatically generated exercises were useful for learning position-based processes: "The interactive one is obviously very necessary. [...] I personally like physical interaction so when I teach data structures in person, I will often bring like puzzle kits and stuff that people can play with." (P9)

The ability to generate exercises following specific pedagogical procedures was also highlighted as valuable: "It is following some kind of learning procedure, which right now the other tools don't have, which is the [...] demonstration of how to do something first, and then to be able to be quizzed or to be posed a question at the end of it. I think that part is also pretty useful." (P10)

Moreover, the provision of immediate feedback in the learner exercises enhances learning: "If you're not doing it right, it just basically won't accept it. So it kind of gives you immediate feedback that you're missing something. And that should hopefully encourage people to go back and look at the demo part again. Say okay I missed something, let me go back and figure out what I did wrong. So I think that's really good to have that sort of immediate feedback." (p9)

5.5 Limited Learning Scenarios Due to Interaction Implementation

This theme shows how XRAuthor, while efficacious in specific learning scenarios, has significant potential for expansion beyond the specific interaction designs implemented in this study.

A majority found XRAuthor "useful for step- and puzzle-based learning scenarios" (13/14). Notably, it was found to be most effective in technical computing subjects (we acknowledge that this observation may be influenced by the choice of the sample lesson used): "Like data structures and all those things, it makes a lot more sense, because students can, like, interact and do things, right, which is difficult, otherwise, for them to understand paper and pen." (P4)

XRAuthor was also recognized to be useful for conveying less technical concepts requiring steps or movement of objects, e.g., software engineering processes: "I teach agile game development, which means students have to make a list of user stories, and then they have to plan the sprint. And that it's a bit of a visual exercise where you make a list of cards on one side and you move them onto a task board. So I can see myself using this to explain the methodology of how a task board is used in a giant game development process." (P12)

Many also expressed how XRAuthor's "application needs to be extended" to cater to broader scenarios (8/14). Some suggestions were related to limitations in the current version: "I think many of the interactions here are more like position. And I guess I'm guessing this is a more like a two dimensional positions." (P3)

Participants also highly regarded XR content and expressed a desire for more immersive forms of generated content: "I see the biggest value actually in the mixed reality or augmented reality portion of it, right, and the biggest value will be able to, you know, have this interaction, like what you're demonstrating right now, to have this in the headset, and for you to be able to repeat that in a 3D manner, that will be useful, right, for something like repetitive training, right, and that requires a spatial (relation)." (P10)

Others called for a wider range of topics to be covered, alongside more diverse types of learning activities: "For now, I think it's just very easy to demonstrate simple algorithms and something, sort of thing like that, but maybe could have some creative way of doing other stuff as well." (P6)

6 Discussion

The results unveil significant insights into how tools like XRAuthor can serve educators in interactive content creation across different immersion levels. In this discussion, we will position our findings within the current state-of-the-art and underscore how this study contributes to design knowledge in authoring tools supporting multiple immersion levels.

6.1 Relevance of Multiple Immersion Levels for Educational Tools

There was a strong consensus on the advantages of offering multiple formats (Section 5.1), emphasizing the importance of incorporating differing immersion levels to cater to diverse learner profiles. The data also highlighted how learning content needs to be tailored to topics being taught and learners' prior knowledge. This concurs with research showing that the effectiveness of XR learning content across different immersion levels is highly dependent on the learning context and prior knowledge of the learners [33].

Accessibility concerns that surfaced in our data (Sections 5.1 and 5.2), including XR content compatibility across devices and the importance of integration with existing platforms, also align with findings in prior literature [1, 21]. Our study builds upon this foundation by demonstrating how XRAuthor's design can be an initial accessible and versatile exemplar framework, addressing educator challenges to facilitate learning across multiple immersion levels.

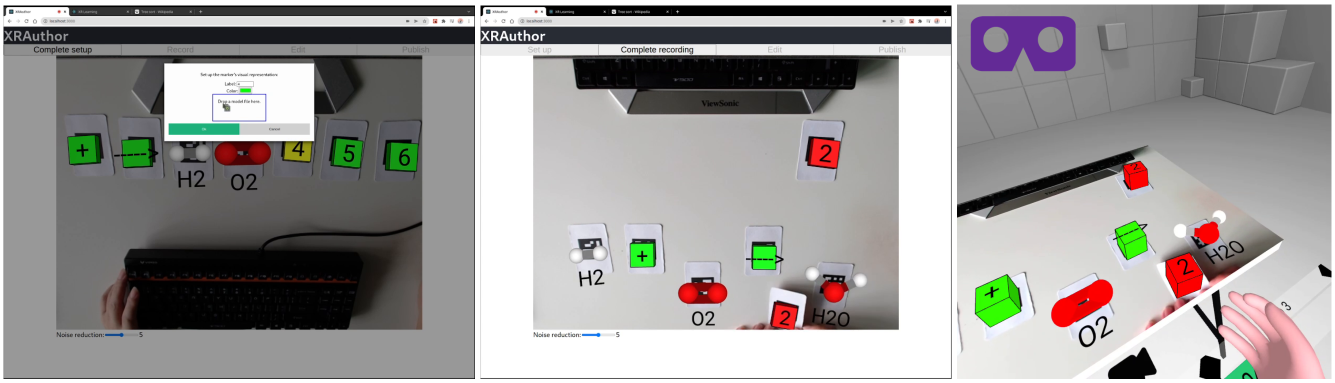
6.2 The Role of Interactivity in XR Education

The recognition of interactivity as a valuable component of XRAuthor's generated content (Section 5.4) is in line with prior research that emphasized how interactive learning elements can enhance engagement and provide immediate feedback to learners [2, 12, 39]. Our study strengthens this notion from the educator's viewpoint by illustrating how XRAuthor's design empowers educators to integrate interactivity seamlessly into their XR content.

Additionally, other than simply striving for more interaction, our findings further adds knowledge on how having multiple varied levels of interaction tailored to distinct immersion levels can be beneficial for educators (Section 5.1). The emphasis on providing diverse learning experiences, from MCQs (for lower immersion formats) to spatial VR tasks (for higher immersion formats), echoes the long-standing principles of learner-centered design, fostering engagement and deeper understanding [4, 14].

6.3 Importance of Ease of Use and Efficiency in XR Content Creation

The high ease of use and efficiency reported with our early version of XRAuthor (Sections 5.2 and 5.3) highlights the potential large impacts of such designs moving forward. This aligns with the broader trends in XR tools to improve usability for non-technical users. However, existing consumer tools (e.g., 8th Wall [22]) and research artifacts are mostly focused in non-teaching domains and do not offer multiple immersion formats [6, 7, 9, 15, 19, 20, 27, 28, 36, 38, 40]. To the best of our knowledge, XRAuthor is the first tool that enables educators to create content across multiple immersion levels with both ease and efficiency. In particular, leveraging commonly used teaching resources and practices is strongly supported by educators. They generally viewed XRAuthor as filling this gap by providing an educator-centric tool that aligns with the broader philosophy of enhancing ease of use and efficiency over traditional XR tools. This emphasizes the need for such XR tools to be designed with



(a) (b) (c)

Figure 3: An example lesson on molecular equations. An author configures virtual objects with 3D molecule models (a), records the lesson (b) through the tool, and examines the generated content in VR on a Meta Quest headset (c).

educators in mind, ensuring that they are user-friendly and efficient for content creation across multiple immersion levels.

Our findings also reinforce the recurring challenges of using conventional XR tools identified in prior research [1, 21]. The findings further emphasized how XRAuthor paves the way to address these concerns, to allow those with limited technical expertise to effectively and efficiently create XR content using XRAuthor, potentially lowering the barriers to entry for educators.

6.4 Scope of Application

Our results illuminate the limited application domain of automatic XR content generation, due to the constraints of the immersive interaction designs supported by the current version of XRAuthor. For instance, XRAuthor cannot provide higher levels of immersion affording 3D object manipulation in virtual environments, which some participants desired (Section 5.5). However, XRAuthor was found to excel in step- and puzzle-based learning scenarios, especially within computing (Section 5.5), similar to prior research that highlighted XR's efficacy in topics that involve spatial reasoning and logical sequences [16]. The design is also well-suited for learning activities in other disciplines that involve similar interaction types, such as chemistry lessons on constructing molecular equations (Figure 3).

Our data also shows a consensus, given XRAuthor's open-source nature, that there is tremendous extensibility to accommodate a broader range of subjects and learning activities (Section 5.5). This aligns with the evolving landscape of XR in education, where diverse topics and adaptive content tools are becoming increasingly relevant [10]. Furthermore, to broaden the application domain and support additional immersion levels, future iterations of XRAuthor could consider incorporating more advanced tracking techniques to enable interactive manipulation of objects in 3D space, as suggested by participants.

7 Conclusion and Future Work

We have introduced XRAuthor, a pioneering web-based authoring tool that simplifies the creation of learning content across various immersion levels - from traditional video to interactive animation and full-fledged VR.

Our study with 14 educators provides empirical insights into challenges, requirements and opportunities for educators (Section 5), offering design knowledge to address these challenges (Section 6). Notably, participants found XRAuthor easy to use, particularly praising its auto-generation feature. The tool's emphasis on diverse interactivity aligns with pedagogical principles, rendering it effective in step- and puzzle-based contexts with extensibility for other contexts.

Regarding limitations, our workshops centered on a computing-related lesson, which might introduce biases. However, we attempted to mitigate this by discussing other lesson types in the workshop. Additionally, while educators did provide valuable learner perspectives, direct exploration of learner viewpoints could strengthen our discussions.

Building on these findings, future work involves gathering perspectives directly from actual learners in a planned study within an actual computer science class. Additionally, we aim to include the developer's viewpoint in extending the tool, as suggested by the data in this paper.

In conclusion, XRAuthor represents a significant step toward bridging the gap between XR's potential in education and its practical implementation. As XR shapes the educational landscape, tools like XRAuthor offer educators the means to harness it for creating diverse, immersive, and engaging learning experiences tailored to different learners.

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A Tool Implementation

XRAuthor is developed as a web application with the following key components:

- Marker detection and pose estimation:
  Leveraging Emscripten, we transpile the OpenCV library with the ArUco module from C++ to WebAssembly. This enables the extraction of marker matrices from a webcam's video stream within a web browser environment.
- Virtual object overlay on videos:
  We utilize three.js to convert matrices from camera space to scene space, facilitating the overlay of virtual objects onto video content.
- Animation and activities generation:
  We use three.js to record keyframes of matrices, enabling the generation of interactive animations and activities.
- VR format:
  We employ A-Frame to create immersive VR scenes.
- Web application:
  We use React to create user interface controls and Zustand for state management between components.
- Backend server:
  We deploy Node.js and Express to establish a robust backend server.

These components collectively enable the authoring workflow that illustrates how educators can have an accessible and efficient tool for creating interactive learning content across various immersion levels.

B Objectives of Using XRAuthor

Table 2: Objectives of Using XRAuthor

Objectives	Description
Author UI	
Edit steps	Use editing UI to segment the recorded video footage into steps.
Edit comments	Use editing UI to add comments for learners.
Preview	Watch the steps and complete auto-generated tasks and questions for each step. Adjust steps where necessary.)
Publish	Publish the generated learning content online.
Learner UI	
Review	Review the contents in multiple formats from learners' perspective.

C Interview Questions

Table 3: A sample of the interview questions.

Dimension		Questions
Usefulness	1	Do you think the tool is useful for your teaching?
	2	Which features do you think to make it useful?
	3	Imagine you're using the tool in your teaching, what kinds of learning content would you like to create in this new way of authoring? And why?
	4	What features or improvements do you think could make the tool more useful?
Ease of use	5	Do you think the tool is easy to use, compared with the existing tools, the tools you've used or usual video recording?
	6	Which features do you think are easy or hard to use?
	7	Based on your authoring experience, what features or improvements do you think could make the tool easier to use?
Efficiency	8	Given that the tool could generate multiple formats of interactive learning content, do you think the tool is efficient for authoring learning content?
	9	Which features do you think to make it efficient?
	10	If you use the tool for your teaching, do you think it will save time and effort for authoring? And why?
	11	What improvements or changes do you think could be done for efficiency?
Effectiveness	12	Imagine you successfully use the tool to author learning content for your teaching, do you think multiple formats and the interactivity of the content will be helpful to your students?
	13	What features do you think can make the content effective?
	14	What subjects or types of learning do you think are suitable for the tool to generate efficient content?
	15	Regardless of authoring difficulties, what kinds of content would you like to create to effectively help your students?
Preference	16	What do you like the most about the tool?
	17	What do you like the least about the tool?
	18	Imagine without usability issues, how would you use the tool in your teaching? What is the preferred way to use it? Will you use it mainly for recording enhanced videos, fast demonstrating, generating interactive exercises or creating immersive experiences?
	19	What's your favorite way or tool for authoring learning content? How do you think it could be integrated with the tool?
	20	What potential features do you need most for authoring?