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Immersive Learning Research Network

Circles: A Framework for Creating Inclusive Virtual Reality Learning Activities in Social Learning Spaces

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Abstract. This paper describes a practical framework for creating inclusive virtual reality learning activities called Circles. Researchers built Circles to address greater engagement and inclusion within virtual reality learning, explore alternative virtual reality learning foundations, and disseminate the design decisions behind creating a virtual reality framework to enhance rather than replace existing social learning spaces. This paper highlights the framework's experiential learning opportunities and contributions to enhance collaborative learning and increase individual and social inclusion in virtual reality learning activities. These features include supporting multiple virtual reality platforms, connecting different virtual learning environments, supporting symmetric selection interactions, and a networking system to enable collaborative interactions. For preliminary evaluation of the Circles framework from a creator perspective, we summarize and analyze several post-secondary education use cases of the Circles framework and semi-structured interviews with eight creators. The emergent themes from this exploratory analysis suggest that Circles provides a good foundation for social multi-platform virtual reality for learning but that more research in exploring transformational learning and more accessible creator workflows is necessary.

Keywords: Virtual Reality, Design, Inclusion, Social Learning Spaces, WebXR.

1 Introduction

Within social learning spaces, such as post-secondary education (PSE) classrooms and museums, where we learn together and alone across physical and digital mediums [1], the social aspect of education is vital, requiring communication and collaboration over increasingly diversified groups [2, 3]. As a potential solution, researchers observe that virtual reality (VR) facilitates experiential learning, promoting active participation and problem-solving so that learners can apply knowledge in simulated real-world or imaginary scenarios [1]. Additionally, studies into using VR to enhance perspective-taking, whereby individuals learn to better empathize with others [4, 5], suggest that VR is a good candidate for promoting transformative learning, whereby learners use critical thinking to support introducing a new way of thinking and knowing [6, 7]. However, contemporary VR learning often focuses on head-mounted displays (HMDs), which creates inclusion challenges such as cybersickness [8], infrastructure constraints [9], various ability and gender biases [10], and social anxiety [11], and do not consider the socio-cultural properties of the social learning spaces that learners use VR within [1].

This paper describes a practical VR learning framework, Circles, and how it provides an entry point for end-user developers (or "creators" as we will describe them in this paper to include designers) "who have little to no technical training in the relevant technologies and programming frameworks" [12] to create inclusive VR learning activities in social learning spaces. We define inclusion as "using proactive measures to create an environment where people feel welcomed, respected and valued, and to foster a sense of belonging and engagement" [13]. Circles is built using the WebXR API as a foundation to support equivalent social VR experiences across multiple VR platforms (HMD, desktop, and mobile) for greater inclusion of learners unable to use HMDs [1, 14] using web technologies familiar to learning institutions.

WebXR has only recently been targeted in research [15], with most studies focusing on using the now-discontinued Mozilla Hubs platform [16] for conferences [17] and classrooms [18, 19], leaving room for more diverse studies into how other WebXR frameworks serve as learning tools. Current WebXR research [15, 20–22] observes the potential of people remotely connecting in virtual classrooms and conferences and several technical and usability challenges, e.g., creating a consistent experience across multiple VR platforms is challenging [20]. Additionally, many VR frameworks focus on re-creating physical spaces, have been discontinued [16], and rarely feature closely coupled collaborations, where "tasks require a close coupling between the interactions of members of a team" [23]. Alternatively, the Circles VR learning framework focuses on enhancing rather than replacing or re-creating physical learning spaces such as classrooms with a focus on virtual learning environments (VLEs), virtual learning artefacts (VLAs, 3D manipulatable objects containing both narrative audio and text descriptions) to increase perspective-taking for transformative learning, and collaborative interactions.

As researchers built Circles from existing WebXR libraries (e.g., A-Frame), with some early design and development described in past papers [24, 25], this paper focuses on the unique design decisions, elements, and features described in this design overview rather than a specific coding pattern [26]. Our research questions follow:

1. *How do researchers build a VR framework to increase engagement and inclusion within VR learning activities?*
2. *How do alternative VR learning methodologies considering socio-cultural andragogy change the foundation for VR design decisions within social learning spaces?*
3. *How do researchers create a VR learning Framework that encourages transformative learning?*

Table 1. Circles' five guiding principles to increase inclusion are inspired by UDL, UD, RBI, and SIM design principles (described below). These align with Circles' features in Table 2.

Guiding Principle	Description	Design Principle(s) Covered	Circles Feature(s)
Platform Scalability	Supporting multiple VR platforms (desktop, mobile, and HMD).	• UDL-"multiple means of representation" • UD-"flexibility in use" • RBI-"body awareness and skills"	supporting desktop, HMD, mobile display and interactions
Social Scalability	Supporting a variable number of users together and alone, encouraging multi-user interactions.	• RBI-"social awareness and skills." • SIM-" ' socially scalable" • SIM-"socially flexible"	avatar visualization, voice communication, costumes, the networking layer
Reality Scalability	Encouraging the design process to consider physical and virtual realities and their interconnectivity.	• UD-"low physical effort" • UD-"size and space for approach and use" • RBI-"environment awareness and skills"	checkpoint locomotion, multi-platform for social anxiety
Interaction Scalability	Interactions are low physical effort selection-focused scaling to advanced controls for experienced VR users.	• UD-"low physical effort" • UD-"simple and intuitive use" • SIM-"visceral"	symmetric selection interactions, advanced immersive interactions
Information Scalability	Encouraging the use of multiple sensory modalities and consideration of how we communicate information to others.	• UDL-"multiple means of expression" • UD-"perceptible information" • SIM-"visceral"	circles' components for artefacts, text, sound, UI, and 3D models

2 Design Overview

The three primary objectives of Circles are:

1. VR Engagement and Inclusion. Though increased engagement is a commonly noted affordance of VR in learning, increased inclusion is less so. While developing Circles, researchers built a framework that considers engagement and inclusion as core concepts for VR-based learning, building from several existing inclusion frameworks such as Universal Design for Learning (UDL), Universal Design (UD), Reality-Based Interaction (RBI), and Social Immersive Media (SIM). UDL proposes multiple means of engagement, representation, and expression [27]. UD [28] describes more accessible interface and interaction development principles. RBI [29] and SIM [30] design principles highlight the connections between immersive digital content and our bodies, environments, and others. Circles' guiding principles are described in Table 1, extending upon UDL, UD, RBI, and SIM design principles and previously defined inclusion areas such as platform scalability, social scalability, and reality scalability [1] (defined in Table 1).

2. Exploring Alternative VR Learning Foundations. Though most VR educational platforms support experiential learning as a foundation, it is unclear how creators connect these decisions to chosen feature sets [31]. Theoretical foundations within Computer-Supported Collaborative Learning (CSCL) [3] may provide a more complete context for virtual and physical environments in socio-cultural contexts. For example, activity theory proposes that the tools, which can be digital or physical, artefacts, learning spaces, individuals, learning outcomes, and communities are all an interconnected part of the learning process [2]. Furthermore, VR's immersive affordances can help learners reflect on their relationships with the learning material to create new perspectives as a form of transformative learning [6, 7]. Activity theory and transformative learning provide a promising foundation for designing a VR framework that considers how we learn within social learning spaces [1].

3. Exploring an Alternate VR Learning Framework. Many social VR platforms focus on communication and recreational contexts [32]. However, it is unclear why developers made the underlying design decisions for many of these social VR experiences [18, 31]. By building a new ground-up approach to creating a VR learning framework, Circles' researchers can more methodically document the VR learning design process and question underlying assumptions about using VR within social learning spaces from a socio-cultural perspective.

Fig. 1. An example of "Multi-world" interactions where learners can see each other and share VLAs from different worlds (note the homework VLA present in both VLEs).

2.1 Core Elements

The following describes the core elements of the Circles VR learning framework.

- **Circle**: A circle is a collection of learners and VLEs. A "circle" allows a group or "room" of learners to visit each VLE synchronously while maintaining visual contact and communication with others. E.g., multi-world interactions in a circle could involve sharing artefacts in one VLE with a learner in a different VLE.
- **Artefact**: Circles has been developed with social narrative in mind, as storytelling is a powerful teaching tool [33]. There are VLAs (Fig. 1, "math homework") for learners to select, manipulate, and listen/read on to learn more about its relationship to the learning object of the VLE.
- **World**: A world can be any VLE created to share knowledge.
- **Axis**: A "hub" world that connects other worlds to provide a VLE for group processing and reflection, e.g., a campfire VLE (Fig. 1, left).
- **Group**: A collection of users (invited to a circle) that can explore worlds together.

2.2 Core Features

Features expected within existing VR experiences are object interactions, virtual environments, avatar visualization, and communication [32]. We highlight nine additional Circles' features based on socio-cultural andragogy in Table 2.

2.3 Interactions

Circles supports object interaction, viewpoint control, and locomotion across desktop, mobile, and HMD VR platforms. Using symmetric selection-based techniques for object selection and travel allows interaction equivalency across all VR platforms (Fig. 2). Where they cannot be identical, Circles defers to the default equivalent behaviours in the A-frame library, e.g., viewpoint control handled by device orientation on mobile and HMD. Table 2 also notes collaborative interactions built into Circles.

Table 2. Circles has several core features based on the guiding principles described in Table 1.

Features	Description	Scalability Principle
Multi-Platform	Experiences work across three VR platforms (desktop, mobile, HMD)	Platform Scalability
Symmetric Selection Interactions (SSI)	Interactions require only a single selection to use. E.g., select an artefact to pick up, drop, manipulate and click to teleport. SSI helps learners switch between VR platforms and minimizes physical movement, avoiding conflict with the physical environment.	Platform Scalability, Interaction Scalability, Reality Scalability
Advanced Interactions	Some more advanced users wish for more complex controls to be more immersed. E.g., smooth locomotion is triggered with an HMD controller joystick or desktop WASD keys.	Interaction Scalability
Circles Artefact	Knowledge transfer focuses on VLAs that users manipulate to access textual, audio, and visual information about the learning subject.	Information Scalability
Multi-world	Circles encourages the creation of multiple worlds to explore different themes within the same subject area, including axis worlds, to connect them all via circles-portals.	Information Scalability, Social Scalability
Axis Worlds	Circles encourages a "hub" world that connects other worlds. These axis worlds, e.g., a campfire, will give learners a natural social reflection and discussion area.	Social Scalability
Multi-World Avatars and Artefacts	Learners can see each other as avatars within Circles' VLEs, even if they are not currently in the same one. They can pass VLAs from one world to another learner in another world.	Social Scalability
Networked Interactions	Circles' includes a system to make networked objects, interactions, and messages within Circles' worlds. E.g., sharing artefacts between each other and connecting interactive and non-interactive objects across clients for more collaborative interactions.	Social Scalability
Roles	Several roles within Circles, e.g., student, teacher, researcher, and participant, allow certain users different abilities or permissions. E.g., only a researcher can collect data, and a teacher can create "magic links" to anonymize others to their group.	Social Scalability

Object Interactions. Circles uses symmetric selections (Fig. 2) for object selection, release, manipulation, and locomotion, i.e., there is similar functionality across all VR platforms. Although different VR platforms have unique interaction possibilities (e.g., HMD hand tracking), selection is a simple way to interact and yield a consistent experience across different hardware [15]. Additionally, selection is critical in social learning spaces where users may not have the physical space or abilities to use immersive physical interactions, such as walking or using their hands to grasp a virtual object [34].

Viewpoint Control. Viewpoint control is the "task of manipulating one's perspective" [35], i.e., the user can control what is seen in a VLE. Circles uses familiar behaviours of mouse-drag for desktop and device orientation for mobile and HMD. Researchers also added "snap-turning" [36] for advanced VR users. However, in the future, Circles’ researchers will explore selection-based viewpoint control for learners with more significant physical challenges [34] and explore varying options for mobile users who may find holding a mobile device up for an extended time uncomfortable [37].

Fig. 2. From left to right, symmetric single-selection interactions are showcased on desktop (mouse click), mobile (finger-tap), and HMD (controller trigger-click on ray cast selection).

Locomotion. Following the selection design philosophy, travel in Circles also employs selection. As Circles’ researchers assume that users within social learning spaces will have minimal physical space, users can select green circles (Fig. 3) on the floor for "target-based travel" [35]. The green checkpoints also help users wayfind as "local landmarks" that help users visualize where they can travel in the VLEs [35]. Although teleportation is the primary locomotion technique, the desktop and HMD additionally support "smooth locomotion" using the keyboard for desktop VR, and the motion controller joysticks on HMD VR for advanced users.

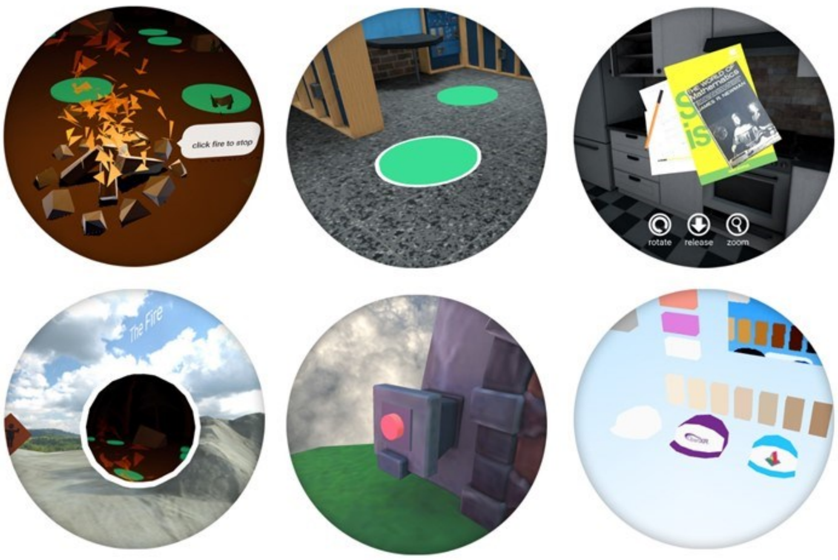

Fig. 3. Basic symmetric selection-based interaction objects, from top-left to bottom-right: an interactive object, teleport checkpoints, a Circles' artefact (select to pick-up, and use buttons below to manipulate and release), a hyperlink portal to another VLE, a simple “circles-button” trigger, and a hat “costume” object to change avatar appearance.

2.4.4 Collaboration

Circles’ researchers argue that supporting collaboration is crucial in social learning spaces, and adding tools to support closely coupled collaboration will enhance learning [3]. Situated learning theories posit that learning is affected by the socio-cultural environments in which we learn [2]. Circles includes the following collaboration features.

- **Group Reflection:** The campfire axis world provides a universal communication space to reflect and process what learning has happened in other worlds to increase critical thinking and transformative learning [6].
- **Artefact Sharing:** Learners can select and pick up an object to show learners in other worlds, who can also see, select, and manipulate the artefact to foster discussion and collaboration among learners (Fig. 1).
- **Role Play:** By selecting various costume objects within selected Circles' worlds, learners can better embody roles within the learning narrative to help increase perspective-taking.

- **Custom Networking:** Send small messages and javascript objects to other clients, including multi-client synch events for closely coupled interactions.

2.4 Technology

Researchers built Circles on top of the existing WebXR libraries A-Frame and Networked-Aframe, inspired by earlier versions of Mozilla Hubs, to maintain familiarity with existing A-Frame libraries and Javascript components. Circles connects A-Frame, Networked-Aframe, a Mongo database, and a Node.js server to provide additional networked and non-networked components, multi-world elements, and interactions for more collaborative experiences. Circles targets HMDs, mobile, and desktop PCs running Chrome-based browsers.

2.5 Components

Creators can create and use A-Frame-based components. Circles also provides several components to support social learning interactions. The following is a subset of the available Circles' components.

- **circles-artefact:** Explores manipulatable storytelling-based learning with knowledge-based VLAs. These VLAs include text and audio descriptions.
- **circles-checkpoint:** Attach to an entity to act as a locomotion checkpoint.
- **circles-interactive-object:** Attach to an entity that you wish to be interactive and add visual feedback to the object, i.e., hover effects like an outline or highlight.
- **circles-pickup-object:** This component lets you select, manipulate, and release virtual objects on selection. The "circles-pickup-networked" component extends to add networked capabilities to share objects with others.
- **circles-portal:** A simple component that creates a sphere that can be used as selectable hyperlinks to travel between VLEs.

3 Circles Use Cases

This section briefly describes several Circles' VLEs created within various learning contexts. Please note that these are all exploratory use cases of Circles, with some cases featuring further detail in other papers.

3.1 Viola Desmond (2019)

Fig. 4. Developers created three Circles' worlds to describe Viola Desmond's story.

Viola Desmond was a Canadian Civil Rights pioneer, and researchers worked to help tell her story during Circles' initial design and development [24]. The original HMD target was the low-powered Oculus GO, with one controller and no positional tracking. Thus, much of the initial work focused on optimizing worlds for low-powered devices, simplifying interactions, and defining a 3D asset creation workflow. Researchers observed that users found the storytelling-based VLAs engaging during development. Hence, Circles' researchers developed the "circles-artefact" component to help encourage creators to implement VLAs/Artefacts in future projects.

3.2 Women in Trades (2021)

Fig. 5. Creators created three Circles' VLEs to highlight women's trade challenges.

These VLEs were created for a PSE faculty workshop highlighting women's challenges in the trades. Developing assets for a more powerful HMD (Meta Quest 1) allowed creators to implement higher-resolution textures and 3D models. Creators designing and developing VLES and VLAs taught researchers how to work with inclusion and subject matter communities to design VR content and better refine Circles' documentation, components, and content creation pipeline. The authors are preparing a full paper detailing the results of a study conducted using these environments.

3.3 Kinematics (2022)

Fig. 6. Creators created three different Circles' VLEs to help introductory physics students.

Creators developed kinematics VLEs for an introductory PSE physics class. The creators were creative in building around the performance limitations of mobile HMD platforms by using simple colour and text. This project's development helped refine Circles' to include desired functionality, such as "naïve physics" [29]. Creators developed this content under the supervision of a Physics instructor.

3.4 Research Projects (2022-2023)

Fig. 7. From left to right, three studies use Circles to create a symbolic memory palace for an introductory cognitive science course, a community co-design study with a local indigenous group, and a virtual recreation of a university campus.

Researchers created a Circles world for use within cognitive science classrooms to help students understand the function of parts of the brain as illustrated metaphors [38]. Other researchers collaborated with a local indigenous group to explore how to co-design VR content [39]. Another project is re-creating a university campus. These projects helped researchers better understand how to support new creators [12]. They were essential in helping researchers better document the setup process and identify new Circles’ components for development.

3.5 Student Creator Projects (2023)

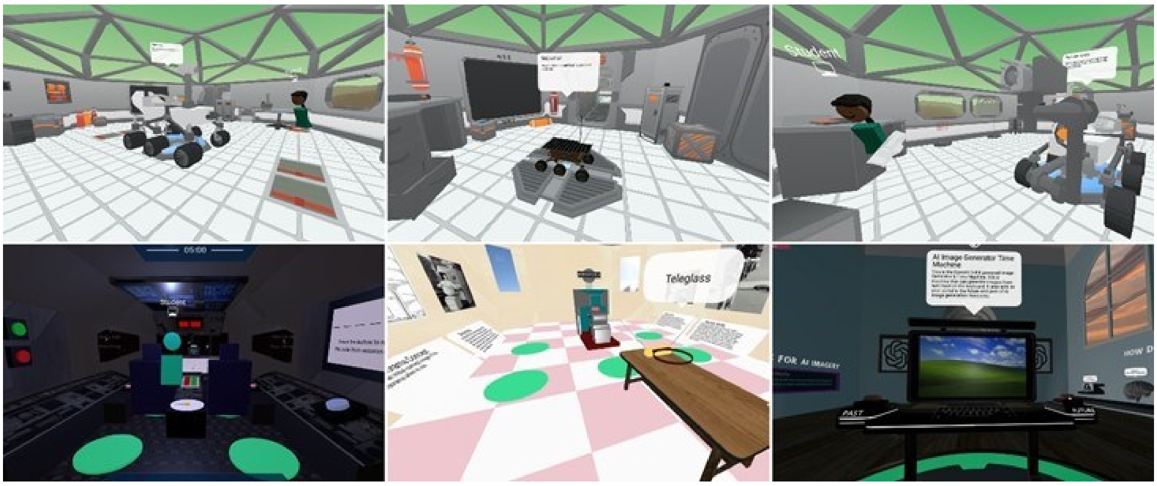

Fig. 8. Several student projects used Circles to create virtual learning experiences centred around the themes of space travel, VR history, and AI history.

As part of a pilot into having other creators use Circles to create various learning-focused worlds, several small student groups of four or five members created space-themed, VR-themed, and AI-themed worlds throughout a semester-long term project. For many of these students, this was their first experience with using A-Frame and Circles to develop content, and for others, their first introduction to creating VR experiences. While observing development, researchers learned to further abstract networking functionality and JavaScript coding principles to make implementing more complex and exciting multi-user collaborative interactions easier. The findings from student creator experiences will be the subject of another paper after another round of in-class use for Circles.

3.6 Other Worlds (2020-2023)

Fig. 9. Circles VLEs for examples and research. From left to right, an "example world" showcasing Circles components, an "example networking world" showcasing Circles' networked components, and a selection and search "research world."

Researchers developed three other Circles worlds to help showcase how to use various networking and interaction components and to perform remote Fitts' law selection and search studies [15, 40]. The development of these worlds helped researchers better explain how to use Circles' components while also exploring the ability to have different VR users with associated privileges and roles, e.g., data-collecting researchers and participants.

4 Creator Interviews

To help with further understanding of how creators used Circles to create social multi-platform VR, researchers conducted semi-structured video-conferencing interviews with eight creators who used Circles to build the "research projects" (Section 3.4) and "student creator projects" (Section 3.5). All participants were university students aged 20-23 (3 men, 5 women) selected via purposive sampling. Researchers recorded answers via notetaking during the interviews and analyzed content post-study, looking for themes with an emergent coding approach [41]. Though the study is preliminary, it helps to set future development objectives to improve the usability of the Circles framework for creators. The five questions that guided the interview process follow:

1. What is your general/overall impression of using the Circles VR learning framework?

2. How easy/difficult is the framework to use?
3. How does using Circles compare to creating educational Virtual Reality development without the framework?
4. What features would you like to see added/modified?
5. Any additional comments?

In the researchers iterative coding process, positive themes identified included "easy-to-use," "enjoyable," " helpful components," "liked example worlds," and "would use again." Negative themes identified were "debugging difficult," "compilation long," "installation difficult," "documentation incomplete," and "content creation challenging." The three primary themes that emerged from these codes follow:

Development: Most creators found the framework easy to use if they had previously used Javascript. However, two participants said they found it difficult to internalize the design patterns of the Circles Entity-Component System (ECS), which is likely due to having limited experience with A-Frame or Unity, both of which also use an ECS coding pattern. Participants found that the included "example worlds" helped their understanding and suggested tutorial videos. All participants found Circles enjoyable and were surprised at how easy VR development can be using HTML and Javascript. However, three participants lamented the difficulty of initially setting up Circles, even with the step-by-step instructions, due to the many dependencies required.

Content Creation: Creating or importing 3D models led to strange scaling, lighting, and performance issues depending on which 3D modelling software creators used. For example, if a 3D model had too many polygons or high-resolution textures, the browser would run out of memory and crash. A-Frame and Circles' reliance on glTF models was considered challenging, as not all 3D modelling software, such as Autodesk Maya, supports the emerging 3D format. This complication led to creators switching between software, such as Blender and Adobe Substance Painter, to export to glTF models.

Documentation: All participants had feature requests centred around making networking easier (as many focused on single-player experiences and often "didn't explore multi-user stuff as much"), making Circles easier to debug, and including more documentation, such as video tutorials. Another common theme was that the documentation provided was helpful but did not sufficiently cover all aspects of the Circles system, leading to confusion about adding custom functionality. Creators wished they had “spent more time understanding” other networked components and the messaging system to create more interesting collaborative interactions.

5 Discussion and Future Work

Referring to our three research questions, we describe our preliminary findings through the design and development of Circles and Circles use cases in section 3.

1. How do researchers build a VR framework to increase engagement and inclusion within VR learning activities? Increasing features while retaining a simple and usable interface and interactions across three different VR platforms requires a delicate balance between creator usability and framework flexibility. Still, Circles provides a solid base for further research and development by focusing on the guiding principles of platform scalability, social scalability, reality scalability, interaction scalability, and information scalability (Table 1). However, we need to explore further the accessibility of other interactions, such as viewpoint control and include more standard web accessibility features, such as contrast and colour adjustment and text reader support, in addition to exploring more advanced locomotion and interaction methods.

2. How do alternative VR learning methodologies considering socio-cultural andragogy change the foundation for VR design decisions within social learning spaces? By focusing on andragogy, which considers how individuals' learning is interconnected with their community, environments, artefacts, tools, and learning outcomes, we can create a more comprehensive use of VR for learning across physical and virtual worlds. Circles enables these connections by focusing on creating interactions mindful of our physical spaces with low-effort symmetric selection interactions and multi-platform VR support to acknowledge social anxiety. Additionally, Circles' focus is on VLAs that can move between different Circles' worlds, helping to share knowledge and allowing unique social interactions.

3. How do researchers create VLEs that encourage transformative learning? From our use case studies and creator interviews, we argue that Circles shows promise as a VR learning framework accessible to creators and promotes more transformative learning with VLEs, such as the campfire “axis world,” creating a virtual space for processing and reflection activities and the women in trades VLEs that enhanced perspective-taking through storytelling-based VLAs. Further formal real-world case studies of the Circles framework in social learning spaces will be necessary. For example, using Circles in more classrooms and museums to evaluate whether transformative learning skills are being enhanced and, if they are, how these effects change across various VR platforms.

In the use case studies and during the Circles framework development, researchers have noted several areas worth pursuing in improving Circles, such as easier installation, better documentation, better guidance on debugging HTML and Javascript and enhancing high fidelity 3D content performance. Continuously working with creators to better understand the development bottlenecks is necessary, as is performing additional studies into how learners use and develop using Circles and other multi-platform VR frameworks to understand better how to make more usable and accessible multi-platform 3DUIs and content creation tools, as well as other social VR considerations such as privacy controls and better non-verbal communication [32].

6 Conclusion

In this paper, we presented Circles, an open-source WebXR-based framework for creating more inclusive and engaging VR learning activities. We described its core concepts, features, and functionality as an example of a VR learning framework focusing on a stronger experiential learning foundation from a socio-cultural andragogical perspective. With this foundation, Circles aims to build more authentic VLEs and VLAS to encourage discussion, reflection, critical thought, communication, and collaboration. Through several case studies and creator interviews, we can conclude that Circles is a good direction toward a practical VR learning framework. However, additional research and development is required to increase the accessibility and efficacy for virtual reality learners and creators, including a more in-depth study of the transformative learning potential.

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