# Sense of Presence and the Illusion of Self-scaling in Virtual Learning Environments

Linfeng Wu, Karen B. Chen(✉), Matthew Peterson, and Cesar Delgado

North Carolina State University, Raleigh, USA
{lwu23,kbchen2,mopeters,cdelgad}@ncsu.edu

**Abstract.** Virtual reality (VR) enables users to have a sense of presence and potentially facilitates effective learning. The research team developed Scale Worlds (SW), a virtual learning environment designed to help learners conceptualize size and scale through virtual shrinking and growing by tenfold increments and experiencing scientific entities at extreme scales. The present work investigated two crucial aspects of experiences in SW: the sense of presence and a novel self-scaling illusion. Participants experienced SW via two devices: a head-mounted display (HMD) with the absence of a virtual body and a Cave Automatic Virtual Environment (CAVE) where participants could see their own physical body. Results showed that participants reported higher levels of presence and more readily felt themselves shrinking and growing in SW-HMD than in SW-CAVE. Findings include factors that contributed to the sense of presence and self-scaling illusion in SW, and implications for designing those illusory experiences in VR across various applications and platforms.

**Keywords:** Virtual Reality · Presence · Scale Cognition · Education Application

## 1 Introduction

Virtual reality (VR) has demonstrated effectiveness in education as it enables immersive and interactive learning experiences [1, 2]. In VR, users have reported varying illusory experiences where they felt as if they had entered altered situations and identities, and responded accordingly [3]. The creation of these experiences in VR, such as the sense of presence, can be important to enhance learning outcomes in virtual learning environments by facilitating deeper engagement and active participation among learners, such as hands-on learning experiences and enhanced cognitive processes [4, 5].

Presence in VR is the sensation of being immersed in a computer-generated environment, feeling as if one is truly present in it [6–8]. Presence can be construed as a fundamental manifestation of illusion, specifically the illusion of physical presence despite the conscious awareness of its virtual nature [9, 10], and it thus contributes to the powerful and captivating appeal of VR. With a greater sense of presence, users may perceive VR to be a more enveloping and interactive reality than the surrounding physical world [5, 11]. This psychological experience profoundly affects user engagement, cognition, and emotions during VR interactions [12–14]. Specifically in the context of


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learning, developing a sense of presence in VR can play an important role in enhancing learning outcomes through purposeful design of the learning environment mitigating cognitive load [15, 16]. Studies about formal learning in VR revealed that the association between the sense of presence and learning is positive and has increased as technology has evolved [5].

Learning size and scale has been an important topic in education due to its fundamental relevance across numerous scientific disciplines [17, 18]. Virtual reality has brought new inspiration to learning size and scale since it has the ability to visualize metaphors of intangible abstract science, technology, engineering, and mathematics (STEM) concepts [19, 20] such as creating visual illusions related to size and scale [21]. Studies have shown that individuals' perception of size and scale could be manipulated through the "body scaling effect," which refers to using their own body or limbs to base the size of the environment and nearby objects [22, 23]. Body change illusions (embodying participants in different sizes of virtual bodies) have been used to manipulate the perception of size and scale in the virtual environment [24–27]. In addition, in situations with the absence of a visible body, the perception of size and scale can be manipulated through the visual cues of nearby environmental features [28–30]. Drawing from these insights, the current study addresses the self-scaling illusion in a virtual learning environment called Scale Worlds (SW), which was designed to enhance learning size and scale.

Scale Worlds allows users to shrink or grow by powers of ten and experience entities from molecular to astronomical levels, to address challenges in the conceptualization of size and scale through VR. The present work stemmed from a larger user experience study that evaluated the usability of SW. In this paper, we focus on examining participants' sense of presence and self-scaling illusion in SW-HMD and SW-CAVE. By examining both quantitative and qualitative measures, the present work discusses the influence of these factors on users' perception and its implications for designing effective and impactful immersive virtual learning environments.

## 2 Related Works

### 2.1 Presence, Immersion, and Learning

In the context of VR, presence refers to the subjective feeling of "being there" in the virtual environment, to the extent that the individual perceives and interacts with a virtual space as if it were real [12, 13]. The sense of presence is a fundamental factor influencing a user's engagement, cognitive processes, and emotional responses during VR experiences [31, 32]. In relation to learning in VR, the sense of presence is connected to selective attention, which reduces the processing of distractions and thus enhances memory encoding [33]. A systematic review on the relationship between the sense of presence and learning in VR has shown that presence can enhance learning and has the potential to give a virtual experience the same value as a corresponding real one [5]. In contrast to the subjective nature of presence, immersion refers to the quantifiable characteristics of VR technology, which may support users in developing a sense of presence in VR [14, 34]. The assumption is that greater levels of immersive quality can lead to increasing sense of presence [35], and a meta-review has further identified specific characteristics of VR technology that have a relatively greater impact on the sense of presence, including user-tracking, utilization of stereoscopic visuals, and wider visual display fields [36].

Different VR hardware devices and systems may have different immersive qualities, which may lead to users' varying sense of presence [37]. Head-mounted displays provide individual users with a more personal and enclosed VR experience, and augment users' sense of presence through advanced tracking mechanisms and stereoscopic displays that precisely synchronize visual and auditory stimuli with users' head movements [38, 39]. On the other hand, cave automatic virtual environments (CAVEs), which employ multiple projectors in a room-sized enclosure, utilize active shutter glasses and precise tracking of user movements to enable a shared experience among multiple users within a physical space with a broader field of view and greater interactivity [40, 41]. While a study by Juan and Pérez [42] compared CAVEs to HMDs and found that CAVEs elicited greater presence and anxiety for acrophobia-related scenarios, another study indicated the difference in terms of features like immersion, presence, or other perceptual illusions between head-mounted displays (HMDs) and CAVEs were inconclusive [37]. The current study aimed to investigate participants' sense of presence across the two different versions of SW and to discern any potential factors contributing to the sense of presence in SW.

### 2.2 Visual Illusions Related to Size and Scale in VR

Understanding size and scale perception of objects in VR has become an active research topic and previous research has shown that visual cues of size in VR can affect the perception of sizes and distances [30]. It is known that people tend to use familiar objects, such as their own bodies or limbs, as references to compare with less-known features of the environment. This phenomenon is often referred to as the "body scaling effect," through which people base the size of the environment and nearby objects [22, 23]. Users can embody virtual bodies of different sizes and possibly develop body change illusions, which may produce changes in perception of size and scale in VR. Studies have shown that body change illusions impact size perception in VR environments, where objects may appear larger or smaller than their actual physical counterparts [24, 27]. A study about embodying an adult within a child-like virtual body has shown that people's mental representations of their own bodies and size perception are malleable through sensory cues in VR [24]. Study by Normand et al. [27] about body change illusion showed that multisensory stimulation can induce an illusion of larger belly size in VR and suggested applications including treatment for body size distortion illnesses.

In addition to having a visible virtual body, another way to influence the perception of size and scale is by manipulating the visual cues within VR. Individuals' object size estimations are affected by manipulating the size of nearby objects or the environment [30]. Furthermore, the effects of stereopsis on vection in VR indicate that a self-motion illusion could be created by rotating the visual cues of surroundings [43, 44]. Similarly, the team aimed to create a self-scaling illusion for participants in SW by manipulating the features of the environment, such as scaling animations of the environment from the backend transitions.

### 2.3 Scale Worlds for Learning Size Through Scaling

The exploration of size and scale is a pivotal subject of study due to its fundamental relevance across numerous scientific disciplines and its impact on our understanding of the physical world [17, 18]. Scale Worlds encompasses a wide range of scientific entities of different sizes that are distributed among distinct environments or "scale worlds" [45, 46], each of which corresponds to an exponent in scientific notation. In SW, the environment was designed to be a single, internally consistent world to provide an allocentric point of view, and the user is the only entity that is inconsistent (shrinking and growing). Similar to the vection illusion, it was intended for the users to evoke the illusion of self-scaling (i.e., feel they have shrunk or grown) when going to different scale worlds, as opposed to users noticing the environment (e.g., entities, posts, grids, floor) changing. This approach was adopted to ensure that participants could authentically experience scientific entities at extreme scales, as opposed to merely observing 3D entity models scaled to certain sizes. Thus, SW was purposefully designed to elicit self-scaling illusion, with environmental elements and design attributes strategically employed to support it.

Previous investigations primarily utilized HMDs and involved the concept of body scaling effect to induce the body change illusions in VR [24, 27]. Though research has shown that the body scaling effect exists even when the body is not visible [28, 29], there is limited research in this area when there is no virtual body present, and there is a paucity of studies conducted within CAVE systems where users could see their physical bodies. The current exploratory study preliminarily examined whether the illusion of self-scaling can be induced within SW-HMD, which lacks a virtual body presence, or in the SW-CAVE setting, where participants have visual access to their physical bodies. It explores the relationship between the sense of presence and the illusion of self-scaling in SW-HMD and SW-CAVE, and whether and how this relationship differs across platforms, along with the perceived advantages and disadvantages of the two versions regarding learning size and scale. The investigation holds significance as it could offer valuable insights aimed at enhancing learning outcomes within virtual learning environments through different VR technologies.

## 3 Methods

### 3.1 Participants

Fifteen first-year college students participated in this study (age $18.8 \pm 0.56$, six female, nine male). The rationale behind selecting first-year college students as participants stems from their status as a representative cohort for exploring size and scale concepts within the college context, as they could enroll in courses such as astrophysics (larger entities) and biochemistry (smaller entities). Exclusion criteria encompassed individuals with a history of epileptic seizure or blackout, propensity for motion sickness, or heightened sensitivity to flashing lights. The user experience sessions were completed in under two hours. All participants provided informed consent, which was approved by the Institutional Review Board of North Carolina State University.

### 3.2 Equipment

SW-HMD was delivered via Oculus Quest 2 and SW-CAVE was delivered via a C4 CAVE. Both versions of SW were developed in and rendered using Unity (version 2021.3.17f1). Oculus Quest 2 (Meta, Quest 2) provides a resolution of 3664 × 1920 (1832 × 1920 per eye) and is equipped with integrated inertial measurement units that monitor the user's head orientation, facilitating the provision of suitable visual perspectives. In SW-HMD, the participants interacted with virtual entities and the user interface (UI) using the Quest 2 native hand-held controller. The CAVE (Viscube, Visbox, St. Joseph, IL) in the current study comprises three walls and a floor, employing four stereoscopic projectors with a resolution of 1920 × 1800 (Barco F50, Barco) to generate images on corresponding surfaces. Real-time tracking of the user's active shutter 3D glasses is managed using a motion tracking system (DTrack 2, ART GmbH) (Fig. 1). Interaction is enabled through a wand, enabling manipulation and engagement with the UI.

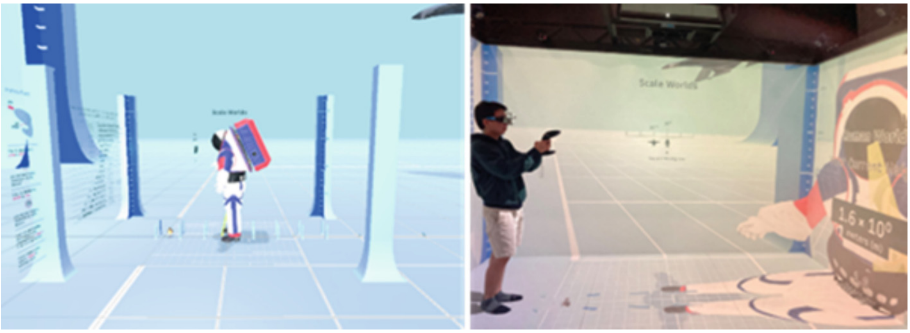

**Fig. 1.** A screenshot in Unity of SW-CAVE (left) and a user holding the wand in the CAVE and being in the Human World (right).

### 3.3 Procedures

Upon obtaining participants' consent, the researcher introduced SW and provided an overview of the study: to understand students' experiences when using SW. Participants first experienced SW-HMD, followed by SW-CAVE. This sequence was dictated by the inclusion of a tutorial session within SW-HMD, because we anticipated SW-HMD to function as a standalone product to be distributed to learners, requiring minimal guidance from the developers. In contrast, the usage of SW-CAVE was envisioned to be guided by a facilitator during lab tours, leading to the omission of a tutorial session. Teleportation was implemented in SW-HMD to facilitate movement, while in SW-CAVE participants physically walked for movement. Participants spent approximately 25 min experiencing SW-HMD, including the tutorial. They were then directed to complete the Slater-Usoh-Steed (SUS) presence questionnaire [47] on paper to self-report their sense of presence. Subsequently, participants progressed to experience SW-CAVE for approximately 20 min and then completed the SUS in relation to their experience in SW-CAVE. Finally, the session ended with a semi-structured interview with a series of inquiries regarding their experience in SW. The semi-structured interview was audio recorded for later data processing and analysis.

### 3.4 Experiencing Scaling in SW

The current version of SW consists of 21 scale worlds ranging from molecular to astronomical levels. Participants were instructed to use either the controller (in SW-HMD) or the wand (in SW-CAVE) to interact with the UI to shrink or grow themselves by a power of ten, which will trigger an animation that proportionally alters the entire environment (including entities, posts, grids, and floor). Positions of the visible entities are ordered logarithmically and approach a zero point, from which all scaling motions are calculated (Fig. 2). In Unity, the position of the zero point is set as (0,0,0) which represents the coordinate origin and the center of the three-dimensional space. The scaling animations of zooming in or out start from this point, growing or shrinking the participant's surroundings, creating an illusion similar to vection [43], which we refer to as the self-scaling illusion. Participants were advised to stand at this point to experience scaling, ensuring that the sensation feels natural. The apportion of scientific entities and the scale armatures (e.g., posts) are designed to reinforce the sense of self-scaling, and to provide means by which users can estimate the size of the entities (and of themselves).

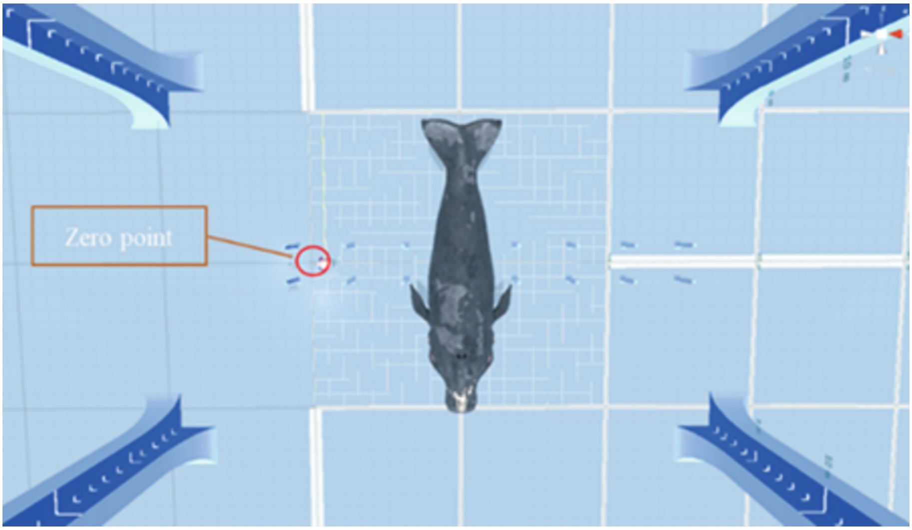


**Fig. 2.** Scale Worlds features to support the self-scaling illusion including entities, posts, grids, and floor.

## 3.5 Variables and Analysis

**Subjective Sense of Presence**
The Slater-Usoh-Steed (SUS) is a presence questionnaire [47] (Table 1) comprising six questions, stemming from three central themes: the perception of being immersed within the virtual environment, the level to which the virtual environment supersedes the real world, and the extent to which the virtual environment is recollected as a distinct "place." Each question was rated on a scale of 1 to 7, with higher scores indicating a higher level of presence.

The SUS presence score was calculated in two ways [47, 48]: mean score and count score. The SUS mean score is the average across the six questions. The SUS count is the number of scores of the six questions, where the responses had a score of 6 or 7 on a 1–7 scale. Both sets of scores are pivotal in assessing the degree of presence experienced by participants within the virtual environment, thereby offering insights into the perceived immersive quality of the VR experience.

**Table 1.** The six questions in SUS.

| | |
|---|---|
| 1. Please rate your sense of being in the VE, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place | |
| (1) Not at all | (7) very much |
| 2. To what extent were there times during the experience when the VE was the reality for you? | |
| (1) At no time | (7) Almost all the time |
| 3. When you think back about your experience, do you think of the VE more as images that you saw, or more as somewhere that you visited? | |
| (1) Images that I saw | (7) Somewhere that I visited |
| 4. During the time of the experience, which was strongest on the whole, your sense of being in the VE, or of being elsewhere? | |
| (1) Being elsewhere | (7) Being in the virtual space |
| 5. Consider your memory of being in the VE. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By "structure of the memory," consider things like the extent to which you have a visual memory of the VE, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements | |
| (1) Not at all | (7) Very much so |
| 6. During the time of the experience, did you often think to yourself that you were actually in the VE? | |
| (1) Not very often | (7) Very much so |

**Semi-structured Interview.** The semi-structured interview (Table 2) centered on students' experience in SW and solicited their insights on the sense of presence, the perception of self-scaling, and the advantages and disadvantages of SW-HMD and SW-CAVE to support learning size and scale. This approach allowed for a comprehensive exploration of participants' perspectives, thereby complementing the quantitative data acquired from the questionnaire with a richer layer of qualitative insights.

**Table 2.** The specific phrasing and language of the three questions asked during the semi-structured interview.

| |
|---|
| Q1. Please explain your ratings regarding "the sense of being there" in the two versions of SW. What things helped to give you a sense of really being in the VE, and what things acted to "pull you out" of it? |
| Q2. Did you feel like you were growing or shrinking, or did you feel like you remained the same and the objects in SW were growing or shrinking? Why? Is there a difference between the two versions regarding this question? |
| Q3. What advantages or disadvantages of the two versions of SW did you notice for learning size and scale? |

Question 1 (Q1) concerned participants' sense of presence for both versions of SW and participants were requested to provide explanations for the corresponding ratings [47]. Question 2 (Q2) concerned participants' perception of self-scaling illusions. Participants were asked whether they felt themselves were changing in size, which yielded a binary response (yes/no). Furthermore, participants were asked to elaborate on what supported them in perceiving such illusions during the scaling process in SW. Question 3 (Q3) concerns participants' perspectives on the advantages and disadvantages of the two versions of SW in terms of learning size and scale.

Qualitative data from the interview underwent thematic analysis. First, all the responses were transcribed into text [49] and then coded and grouped into themes [50, 51]. Themes characterized participants' experience in SW including the sense of presence, self-scaling illusion, and the advantages and disadvantages of the two versions regarding learning size and scale. In addition, participants' sentiment (e.g., liked/disliked, advantages/disadvantages) were teased out.

## 4 Results

### 4.1 Presence Score from SUS

The SUS mean scores were 4.80 $\pm$ 0.97 and 4.45 $\pm$ 1.08 for SW-HMD and SW-CAVE, respectively. The SUS count scores were 3.47 $\pm$ 1.45 and 2.50 $\pm$ 1.69 for SW-HMD and SW-CAVE, respectively.

### 4.2 Illusion of Self-Scaling

Twelve out of the 15 participants (12/15) reported that they perceived themselves shrinking or growing in SW-HMD while six of the 15 participants (6/15) reported the same in SW-CAVE.

### 4.3 Themes from Semi-Structured Interview

For Question 1 regarding the presence scores, five participants attributed the higher presence in SW-HMD to greater immersion. In SW-CAVE, participants reported mixed feelings about the visibility of their physical bodies regarding the sense of presence. Four thought the visibility helped enhance the sense of being in the virtual environment while the other two stated the opposite. Additionally, six participants emphasized that visual limitations, particularly the absence of a ceiling and side walls of the CAVE utilized in this study, contributed to decreased presence.

Regarding Q2, participants attributed the heightened immersion of SW-HMD as a contributing factor to the self-scaling illusion. In addition, six participants emphasized the absence of a visible body in HMD enhancing the sense of presence and the presence of a visible physical body in CAVE decreasing it.

In response to Q3, participants favored SW-HMD for learning size and scale, due to its higher level of immersion and freedom of movement, despite reporting greater eye fatigue. On the other hand, participants appreciated SW-CAVE for its ease on the eyes due to the glasses, as well as the ability to physically walk within it. However, they noted that the CAVE system's cost and space requirements made it less accessible compared to HMD. Further details regarding keywords and their corresponding counts are provided in Table 3.

**Table 3.** Recurring themes extracted from the semi-structured interview. For each question, the recurring themes and their corresponding frequencies noted as counts were listed.

| | | | SW-HMD | SW-CAVE |
|---|---|---|---|---|
| Q1 | Themes (count) | | immersion (5)<br>movement (2) | visibility of physical body (6)<br>visual limitations (6) |
| Q2 | Themes (count) | | immersion (3)<br>no virtual body (6) | visibility of physical body (6) |
| Q3 | Themes (count) | pros | immersion (11)<br>movement (2) | easier on eyes (5)<br>physically walk (3) |
| | | cons | fatigue on eyes (3) | less accessible (2) |

## 5 Discussion

This study investigated the sense of presence and self-scaling illusion in SW-HMD and SW-CAVE, as well as the advantages and disadvantages of the two versions of SW regarding learning size and scale. Through a comprehensive approach that combined quantitative and qualitative data analysis, results showed that participants reported higher levels of sense of presence and more readily felt themselves shrinking and growing in SW-HMD than in SW-CAVE. Noteworthy recurring themes arose from the semi-structured interview regarding the advantages and disadvantages of the two versions for learning size and scale, providing insights for designing the illusory experiences and learning size and scale in the virtual environment across various applications and platforms.

When exploring the immersive virtual learning environment, participants reported a greater sense of presence in SW-HMD than in SW-CAVE. It was natural to speculate the difference in sense of presence between SW-HMD and SW-CAVE was attributed to the different quantifiable immersive characteristics, such as field of view and tracking latency [37, 42]. However, themes from the semi-structured interview revealed additional details that further explained the differences in sense of presence. Participants stated that teleportation in SW-HMD felt "not realistic" thus decreased the sense of presence, which was in line with the studies that have shown teleportation as a type of movement might lessen the sense of presence in VR [52, 53]. While this was not in the originally planned study objective, the semi-structured interview revealed different usage of VR terminologies by the participants. Immersion has emerged as the frequently cited rationale behind participants' sense of presence, yet it was referenced in various contexts. While the present study has used one of the many definitions of immersion (i.e., the objective characteristics of VR technology that allows users to feel as if they are present in a simulated environment [14, 34]), the literature includes different definitions and explanations of immersion [54]. Among those who indicated that SW-HMD provided "better immersion" and that thus they had a higher sense of presence, it seemed that they might have subjectively assumed a positive relationship between immersion and presence. For instance, one participant said, "you're a little more immersed, a little more present because you can't see anything else".

Participants' lack of experience with VR technology and terminologies might have affected the responses regarding the sense of presence. This phenomenon aligns with the argument that it is challenging to measure the sense of presence in VR using post-experience questionnaires since the application of questionnaires typically relies on previous experiences, which does not apply to presence that many people are not familiar with [55]. During the process of understanding the reasons behind participants' sense of presence in SW-HMD and SW-CAVE, it became necessary to examine the context of their verbalization during the semi-structured interview. For instance, participants reported mixed feelings about the visibility of a physical body (i.e., participant's real body) in SW-CAVE regarding sense of presence. Four of them believed that such visibility contributed to a heightened sense of presence, with one participant noting, "being able to see myself in the world." Conversely, the other two participants held opposing views, with one stating, "I'm there in my own physical body, and I don't feel like I'm in a virtual reality system." Certainly, there was a degree of unfamiliarity with VR terminology and concepts among the participants given that out of these 15 participants, 13 had rarely or never used an HMD and none of them had prior experience using a CAVE. In sum, participants' exposure to VR terminologies affected the verbalized responses, which highlighted the need for improved methods of measuring VR presence. And the context in thematic analysis of semi-structured interview data helped clarify the participants' intended meaning.

Scale Worlds intends to enable users to shrink or grow themselves as they travel to different scale worlds that contain scientific entities of size differences in tenfold increments [21]. Through this study, SW successfully evoked the self-scaling illusion with 80% of participants reporting this in SW-HMD and 40% in SW-CAVE. While humans cannot physically change their body sizes by powers of ten, SW enabled the participants to generate perceptual illusions that could potentially deceive their visual senses, prompting them to develop the self-scaling illusion instead of recognizing the environmental changes. The literature has demonstrated that individuals' perception of size and scale could be manipulated through the "body scaling effect" [22, 23], which was mainly accomplished through participants embodying different-sized virtual bodies [24, 27]. The present study did not embody participants in a virtual body in SW-HMD, it even showed users their physical bodies in SW-CAVE, which countered the approach in the literature. Scale Worlds instituted self-motion illusions (vection) to facilitate perspective switches and ultimately to relax the physical motion in VR [43]. The findings from the current study suggest that the self-scaling illusion can occur both without a virtual body (SW-HMD) and in the presence of a visible physical body (SW-CAVE). In addition, participants were more likely to perceive the self-scaling illusion in SW-HMD than SW-CAVE. The responses from the semi-structured interview further supported that a virtual body was not required to induce the self-scaling illusion, and the visibility of the real body as seen in the CAVE could potentially undermine the induced self-scaling illusion.

While it may be intuitive to assume that a heightened sense of presence is a prerequisite for inducing the self-scaling illusion, since participants would seemingly need to feel being in the VE to have the sense of self-scaling, the results challenged this assumption. No significant relationship between the sense of presence and self-scaling illusion was found after accounting for the main effects across HMD and CAVE. The data suggested that the extent of presence, assessed using the SUS, was not a requirement for the manifestation of the self-scaling illusion. This observation aligned with the findings from Q2 in the semi-structured interviews, where the theme of presence did not frequently emerge in explanations concerning the perceived self-scaling illusion. Gonzalez-Franco and Lanier's work on illusions in VR highlights the pivotal role of visual inputs in creating illusory experiences and described the minimum instrumentation requirements to support such illusions [3]. Both SW-HMD and SW-CAVE appeared to satisfy these minimum requirements, providing continuously updated displays with head tracking and congruent sensorimotor feedback. However, in the case of the C4 CAVE configuration, visual inputs were not limited to the VR display but also encompass the physical world, which potentially broke the illusion. During the SW-CAVE experience, participants occasionally experienced breaks in the illusion when they directed their gaze towards the physical world surrounding them. As one participant aptly put it, "In CAVE I could see my body so I can, like, remind myself I'm not changing size." Conversely, the HMD effectively mitigated this issue by isolating users from the physical world, thereby preserving the consistency of the illusion.

There have been studies showing that there is a positive association between the sense of presence and learning in virtual environments [56], where the association between the sense of presence and learning is more frequent using quantitative approaches of learning assessment [5]. While the investigation of the learning outcomes was within the scope of the overarching project, it is not implemented in the current study and should be for future studies. This study opted to garner participant insights through semi-structured interviews. Participants were asked about the comparative advantages and disadvantages concerning the two versions of SW in learning size and scale. While a clear-cut preference did not emerge, participants reported the merits and limitations of each. The recurring sentiment was that SW-HMD offered a more immersive experience compared to SW-CAVE. SW-HMD enabled more unrestricted movement via teleportation, facilitating diverse perspectives from different positions, while SW-CAVE only permitted limited physical movements within a confined space. Participants noted that the comfort of the active shutter glasses used in SW-CAVE contrasted with instances of eye fatigue encountered in SW-HMD. Participants highlighted SW-HMD's greater accessibility as a learning tool for students, which aligns with observations that a CAVE system will cost more and takes up more space [37, 42]. Additionally, participants liked the fact that they could physically walk in the CAVE with one participant saying, "I like it in the CAVE that I can physically walk around the objects to compare and look". In sum, both SW-HMD and SW-CAVE have their respective advantages and disadvantages in terms of a scale learning experience. Future research endeavors should incorporate comprehensive investigations into the learning outcomes of these versions.

## 6 Limitation

Some limitations in this study need to be acknowledged. The configuration of a CAVE can include six walls that surround the user to contribute to the sense of being "inside" a simulated world, creating a more immersive experience [57–60]. However, the absence of two surfaces (one ceiling and one side wall) of the CAVE employed in the current study (Fig. 1), could potentially affect the immersion level of the system and participants' sense of presence in the VR environment.

One other limitation was that this study did not employ randomization for the order the participants would try SW. This was intentional for participants to explore SW-HMD upon following the instructions in the tutorial. It is imperative to acknowledge that this study does not constitute a structured experiment; rather, it yields notable observations and dialogues pertaining to the sense of presence and the illusion of self-scaling in SW. Future research should address these aspects with a comprehensive experimental control, such as randomized controlled trials and larger sample size.

## 7 Conclusion and Future Work

The results indicated that participants generally perceived a higher sense of presence in SW-HMD than in SW-CAVE, as measured by SUS. Additionally, participants reported that they were more likely to perceive the illusion of self-scaling in SW-HMD where a virtual body was absent than in SW-CAVE where the physical body was visible. Employing a comprehensive approach that integrated both quantitative and qualitative data analysis, this study has unveiled attributes of the illusory experiences including the sense of presence and self-scaling in SW through two VR technologies. Although no significant relationship between the sense of presence and the self-scaling illusion was identified in the current study, it is recommended that future research with a larger sample size and a comprehensive experimental design be conducted. While SW serves as a virtual learning environment aimed at facilitating students' understanding of size and scale, this study did not investigate the relationship between the sense of presence, the self-scaling illusion, and learning outcomes, which should be a focus of future research.

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