

"Look at My Planet!": How Handheld Virtual Reality Shapes Informal Learning Experiences

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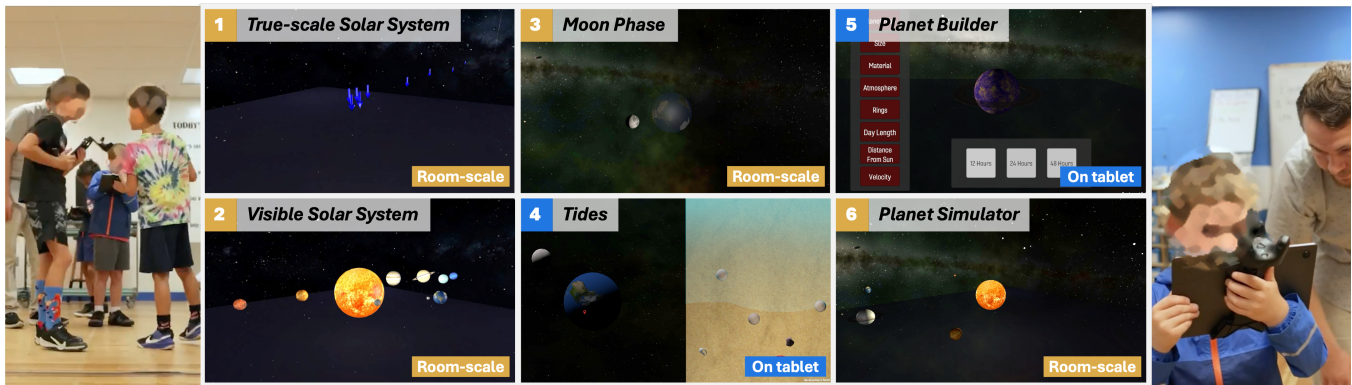


Figure 1: Overview of the *Solar System Explorer* program: On the left, multiple participants engage with the virtual environment in a shared physical space; on the right, a close-up of a participant holding a tablet. The central section showcases captured moments from the six scenes in the program, covering topics of planets in the solar system, moon phases, tides, and custom planet creation.

Abstract

Handheld virtual reality offers a promising tool for fostering engagement in informal learning environments, providing safe, shared, and inclusive experiences. This study investigated the potential of a handheld VR-based educational program, *Solar System Explorer*, in a science museum setting. Fifty-three participants, aged 5 to 13, engaged in six interactive scenes using handheld tablets, involving room-scale exploration of virtual environments in small groups guided by a docent. Findings showed that dynamic, room-scale content encouraged active physical movement, while visually rich, interactive scenes fostered knowledge sharing and elicited positive emotional responses. Social engagement was strongest during creative activities, such as planet building, which facilitated interactions even among unfamiliar peers. These insights inform design guidelines for developing fun, active, and collaborative VR learning environments, contributing to scalable and inclusive handheld VR applications for informal education.

CCS Concepts

• **Applied computing** → **Interactive learning environments; Collaborative learning;** • **Human-centered computing** → *Empirical studies in interaction design.*

Keywords

Handheld Virtual Reality, Informal Learning, STEM Education, Education Technology

ACM Reference Format:

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CHI EA '25, Yokohama, Japan

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ACM ISBN 979-8-4007-1395-8/25/04

<https://doi.org/10.1145/3706599.3720020>

Bennett, Priyanka Nair, Alayna Ricard, Nayha Pochiraju, Daniel Enriquez, Sang Won Lee, Jeffrey Todd Ogle, Phyllis Newbill, and Myoungsoon Jeon. 2025. "Look at My Planet!": How Handheld Virtual Reality Shapes Informal Learning Experiences. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*, April 26–May 01, 2025, Yokohama, Japan. ACM, New York, NY, USA, 8 pages. <https://doi.org/10.1145/3706599.3720020>

1 Introduction

Informal learning environments, such as museums and science centers, offer unique learning opportunities for spontaneous yet meaningful educational experiences [28], contributing to a broader educational ecology [37]. In the context of STEM education, they play a critical role in addressing workforce demands and promoting diversity [8, 20]. Recently, such institutions have increasingly integrated technologies such as virtual reality (VR) to provide an engaging and immersive learning experience [34, 38]. With its ability to visualize complex concepts such as spatial relationships in three dimensions (3D), VR has proven to be particularly beneficial in fostering deeper understanding and curiosity [21].

However, traditional VR head-mounted displays (HMDs) pose several challenges, including barriers for young children and individuals prone to motion sickness [26], as well as concerns about hygiene or appearance in social settings [9]. These limitations have prompted efforts to develop more accessible VR platforms utilizing handheld devices, such as mobile phones and tablets, which act as additional viewports for interacting within the same virtual environment [19, 32]. Handheld devices preserve a peripheral vision of the surrounding environment, reducing safety risks such as collisions caused by the occlusion of the physical environment by HMDs [36]. Prior research has highlighted the benefits of handheld VR in supporting multiple users engaging in a shared space, offering safe and physically active experiences [3]. Despite these advancements, the potential of handheld VR to facilitate engagement in informal learning settings remains under-explored, particularly with a lack of field deployments and accompanying systematic

studies examining engagement across multiple dimensions in these environments.

In the current paper, we present *Solar System Explorer*, an exploratory learning experience developed on a handheld VR platform, tailored for co-located group learners. Using handheld devices, users engaged safely and collaboratively with a shared virtual world while benefiting from 3D learning environments. The platform facilitated embodied learning experiences by allowing users to navigate the space physically while interacting with virtual content through their devices. Additionally, maintaining access to the surrounding physical environment fostered social interaction with peers and educators, which is an essential component of the learning process [30]. The project partnered with local elementary schools and a science museum to showcase the program. The current paper focuses on the initial two-week presentation at a local science museum, where visitors experiencing the program were video-recorded. Our contributions provide insights into the potential of handheld VR to foster visitor engagement across physical, intellectual, emotional, and social dimensions in informal learning settings, especially in multi-user contexts. Our findings offer key considerations for designing active, meaningful, fun, and collaborative learning experiences for young learners, demonstrated through a real-world field deployment.

2 Related Work

In this section, we discuss related work across three key areas central to this research: handheld virtual reality, informal learning, and engagement.

Handheld virtual reality refers to platforms where handheld devices, such as mobile phones and tablets, serve as the primary interface for interacting with virtual environments [12, 17]. While HMDs provide high immersion, handheld devices offer a more accessible and widely adopted alternative. Prior studies have explored platforms integrating handheld devices to observe and interact with VR environments in various contexts, including gaming [14, 19], collaborative work [33, 41], and education [11]. Despite the diverse applications of handheld devices in VR, most research focused on two-person, asymmetrical setups conducted in controlled environments. In a recent study, handheld VR has shown promise in creating more social and inclusive experiences involving multiple co-located users [3]. Yet, limited research has focused on how handheld VR can support group engagement in real-world settings such as informal learning environments, where visitors often engage as part of student cohorts or family groups [39].

Informal learning offers diverse learning opportunities for engagement and exploration beyond traditional classrooms, spanning a spectrum of curriculum formality and learning environments [37]. For instance, museum visits provide non-formal engagement, allowing learners to interact hands-on with exhibits that often align with formal education standards [5]. Such informal learning experiences complement formal education by nurturing curiosity-driven exploration, fostering collaboration, and deepening young learners' understanding of science and technology's role in shaping the society [16]. Moreover, the adoption of new technologies, tools, and practices expands our understanding of informal learning and enhances its integration across STEM disciplines [16]. As technology

advances, immersive 3D environments enable engaging experiences that not only captivate learners but also positively influence their attitude and learning outcomes, highlighting VR's potential as a key enabler in informal STEM education [7, 31].

Engagement in informal learning, defined as the level of visitors' involvement with the content, is a crucial element in assessing the effectiveness of informal learning experiences, which often have multifaceted objectives extending beyond knowledge acquisition [15]. To evaluate engagement in these contexts, Barraiault and Pearons developed *Visitor Engagement Framework* (VEF) [2], which categorizes engagement into three stages: initiation, transition, and breakthrough. Visitors who reach the breakthrough stage are considered to be better positioned to maximize learning opportunities provided by the exhibit. In contrast, Humphrey et al.'s *Active Prolonged Engagement* (APE) framework [23] classifies engagement into four dimensions: intellectual, social, physical, and emotional. Building on these models, Long et al. introduced the *APEX* (*APE eXpanded*) framework [29]. This framework combines the parallel classification of engagement types from APE with the temporal progression of engagement stages from VEF. Tailored for collaborative museum exhibits, the APEX framework systematically examines visitor engagement in group settings, interacting with tangible interfaces over extended periods rather than shorter, individual experiences. For the current study, the APEX framework was chosen as the primary tool for analyzing participant engagement due to its capability to capture nuanced interactions within group-based, shared experiences.

3 Method

3.1 *Solar System Explorer*: Program Overview

Through a collaborative effort by a multidisciplinary research team, we developed an educational program on a handheld VR platform, titled *Solar System Explorer*, featuring six interactive scenes (Figure 1). Each scene was designed to engage users with key astronomical concepts through embodied and hands-on experiences. The first scene, *True-Scale Solar System*, provided a room-scale visualization where planets are shown at their true sizes and distances. This helped users grasp the vast spatial relationships between celestial bodies, highlighting contrasts with typical textbook visuals that often scale distances unrealistically for clarity. The second scene, *Visible Solar System*, showed an enlarged view of planets, resembling textbook visuals, allowing users to examine details of each planet's appearance. The Sun was positioned at the center of the experience area, with planets orbiting around it. Planets up to Jupiter were reachable, while further planets were visible but beyond direct reach. Planetary movements reflected their true relative orbital speeds and scales. In the *Moon Phase*, users observed how the Moon's phases change based on its position relative to the Earth and Sun, offering an intuitive understanding of this celestial process. The Earth was positioned at the center of the experience area, with the Sun and Moon dynamically moving to demonstrate the changing appearance of the Moon. The *Tides* scene illustrated how the magnitude of tides varies across different Earth locations, connecting gravitational forces to observable phenomena. During this scene, the docent selected various cities, marked by a red pin on Earth displayed on the left half of the tablet screen, while the right

half depicted the corresponding tidal changes. In the *Planet Builder* scene, users designed their own planets by selecting features such as size, material, distance from the Sun, and orbital velocity. These choices determined the planet’s appearance and stability within the solar system. Once all users completed their design, the custom planets were integrated into a virtual solar system in the *Planet Simulation* scene. Users could locate their planets based on their unique appearances and observe how the selected features affected their orbit stability and behavior. In *True-Scale Solar System*, *Visible Solar System*, *Moon Phase*, and *Planet Simulation* scenes, users navigated a room-scale virtual environment that was spatially aligned with the physical experience area and synchronized across all users, allowing them to explore a shared solar system freely through handheld tablets. In *Tides* and *Planet Builder*, users interacted directly with content displayed on their individual tablets. Transition between scenes were facilitated by a docent using a designated tablet or a PC running Unity, ensuring seamless progression throughout the program. This approach provided a guided yet exploratory experience, fostering collaboration within a safe and inclusive environment.

3.2 Equipment Setup

The *Solar System Explorer* was developed using Unity with the VIVE Pro 2 system. The setup utilized VIVE Base Stations 2.0 to track the location and motion of handheld devices (Galaxy Tab S7), each equipped with a VIVE Tracker 3.0 attached to a tablet holder. This configuration enabled multiple co-located users to experience the shared virtual environment and interact collaboratively in real time. A single session could accommodate up to eight participants and one docent, all using identical Galaxy Tab S7 tablets. The docent’s tablet included additional features, such as the ability to initiate scene transitions and provide guidance throughout the experience. For the museum presentation, the experience area was approximately 3 meters by 5 meters, marked with black tape on the floor to indicate boundaries. Four VIVE Base Stations were positioned at each corner of the area to ensure comprehensive tracking coverage. Children were instructed to remain within the designated space for safety and optimal system performance.

3.3 Data Collection Procedure

The *Solar System Explorer* was showcased at a local science museum, with participants’ experiences recorded over three days between July 17 to August 3, 2023. Two GoPro cameras were positioned to capture the activity: one provided a top-down view, while the other captured a side-view of the experience area. An additional microphone was used to capture participants’ verbal interactions. Since all participants were minors, their legal guardians were provided with an overview of the research study and signed a parent permission form approved by the Institutional Review Board prior to participation. Participants did not receive monetary compensation but were offered a free admission to the museum. Upon arrival, museum staff escorted participants in pre-determined groups to the exhibit room. Each participant was provided a tablet and instructed to hold it with both hands and remain within the designated experience area at all times. Each group experienced the program for approximately 30 minutes, guided by a docent and supported by additional instructors who supervised the young participants and

ensured their safety. Close collaboration with museum personnel throughout the study period ensured smooth logistics, proper arrangement of the experience area, and effective execution of the program.

3.4 Participants

During the museum showcase, a total of 53 children, aged between 5 and 13, participated in the *Solar System Explorer* program across 13 groups. Of these, 28 children attended as part of the museum’s summer camp program (Groups 1–5), 16 were recruited directly by the research team (Groups 6–11), and 9 belonged to a local summer camp program (Groups 12–13). Group sizes ranged from 2 to 7 children and were pre-determined by summer camp instructors or based on participant availability during recruitment.

3.5 Analysis

Participant engagement was evaluated through video recordings using the coding scheme of APEX framework [29], which examines engagement across four dimensions: physical, intellectual, emotional, and social. The coding scheme was slightly modified to redefine the sub-dimensions of physical and social engagement, ensuring better alignment with the program’s docent-guided, exploratory, and room-scale setting. Video analysis was conducted in 10-second segments using one-zero sampling, where ‘1’ indicated the presence of a sub-dimension and ‘0’ indicated its absence. This resulted in 2,002 annotated segments from 5 hours 34 minutes of video recordings across 13 groups. Each video was independently coded by three researchers: two as primary coders and a third as a tie-breaker for solving discrepancies. Coders also held regular meetings throughout the process to discuss and address potential inconsistencies.

4 Findings

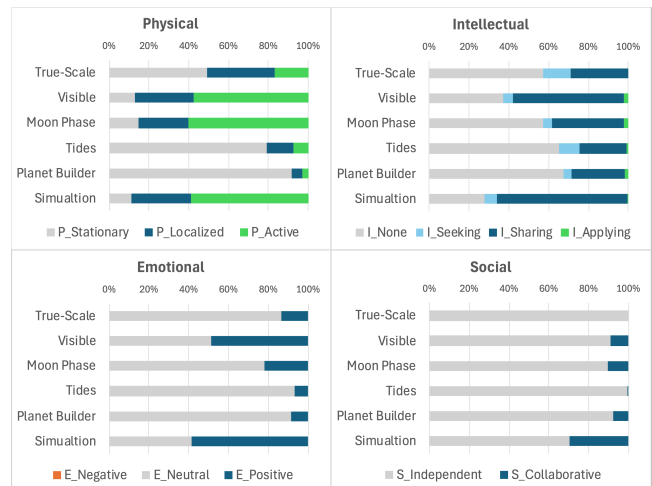


Figure 2: Distribution of engagement across six scenes of the *Solar System Explorer* program for each engagement dimension: physical, intellectual, emotional, and social.

4.1 Physical Engagement

Physical engagement measured participants' movement within the experience area and was categorized into three sub-dimensions: stationary exploration, localized exploration, and active exploration. Scenes featuring dynamic, moving planets in a room-scale virtual environment encouraged substantial active engagement, with participants freely moving around the space. Notably, scenes such as *Visible Solar System* (57% of scene duration), *Moon Phase* (60%), and *Planet Simulation* (59%) had the majority of participant time spent in active exploration. During the *Visible Solar System* scene, one participant in Group 1 enthusiastically said, "I wanna walk through the Sun," held her tablet up, and walked directly toward the Sun, exclaiming, "I am walking through the Sun." Similarly, in the *Planet Simulation* scene, participants walked around to locate their custom planets. A participant in Group 7 approached a planet resembling the one she built during the *Planet Builder* scene, but upon closer inspection, she realized, "Hmm, that's not mine." Shortly after, she identified her planet based on its appearance, exclaiming, "This is mine right here!" Her excitement led her to orbit the Sun herself, mimicking the movement of planets. Active engagement was also observed during the *Moon Phase* scene, where participants physically followed the Moon's orbit. For example, all participants in Group 5 actively chased the Moon as it moved around the experience area, while the docent explained how its position relative to the Earth and the Sun influences its phases. In contrast, scenes that were individually displayed on each tablet resulted in more stationary behavior. Participants spent most of their time in one location during *Tides* (79%) and *Planet Builder* (92%), demonstrating minimal movement and physical engagement. During *Tides*, participants focused on the tablet as the docent selected different cities to demonstrate variations in tidal magnitude. Occasionally, participants glanced at the docent but otherwise remained stationary. In *Planet Builder*, participants were tasked with inputting choices for eight planetary features displayed on their tablets. This activity required focused attention on the screen, leading most participants to remain seated or standing in place. Some participants who finished early moved around, but their actions were unrelated to the program. Overall, scenes with room-scale, dynamic content encouraged notably higher levels of active physical engagement compared to screen-based activities, which primarily resulted in stationary behavior. This highlights the potential of handheld VR-based informal learning programs to foster active physical engagement, particularly through shared and spatially synchronized design.

4.2 Intellectual Engagement

Intellectual engagement measured participants' involvement in learning dialogues related to the program, categorized into three sub-dimensions: seeking knowledge, sharing knowledge, and applying knowledge. Across the program, 86% of the observed dialogue fell into the sharing knowledge category, which included voicing observations, explaining concepts, or describing actions. This was particularly prominent in scenes featuring room-scale, dynamic content with visual planets, including *Planet Simulation* (65% of scene duration) and *Visible Solar System* (56%), followed by *Moon Phase* (36%), *True-Scale Solar System* (29%), *Planet Builder* (27%), and *Tides* (24%). Participants often shared their knowledge by explaining

their actions or observations to others. During *Planet Simulation*, participants were excited to discuss their planet designs. For example, in Group 7, a participant invited her parent to see her planet through her tablet. As her parent exclaimed, "Oh, I love it!", the participant eagerly explained her design choices, detailing why her planet appeared as it did and how these choices influenced its orbital stability. In *Visible Solar System*, participants liked to share what they knew. For instance, a participant from Group 1 explained to others, "All the gas planets are over here, and the rocky planets are there." Similarly, during *Planet Builder*, participants actively responded to docent questions about planet features and explained their own design choices. Sharing knowledge also included voicing observations about objects or actions. For example, in Group 1 during *Visible Solar System*, a participant exclaimed, "Guys, I found United States on Earth!" and "I am stepping on Jupiter!" Similarly, during *Moon Phase*, participants in Group 1 continuously commented on the changing Moon phases. One participant shouted, "Full Moon!" Another participant responded, "No, no, no, it's not. (paused) Now it's Full Moon." Soon after, a participant exclaimed, "It's a New Moon. We have to go this way!", prompting others to follow. Deeper levels of intellectual engagement were less frequent. Seeking knowledge accounted for 12% of observed dialogue, with participants asking questions such as inquiring about the arrows in *True-Scale Solar System* or locating planets in *Visible Solar System*. Applying knowledge, comprising 3% of observed dialogue, involved participants connecting prior knowledge to their observations and planning actions. During *Planet Builder* scene, particularly in later iterations of designing planets, participants demonstrated an increasing understanding of how velocity and distance from the Sun influenced orbital stability. This understanding was reflected in their strategic choices, as they planned their designs to simulate planets with varied outcomes. Overall, the dialogues demonstrated active intellectual engagement, with visually dynamic scenes fostering higher levels of knowledge sharing and excitement for understanding and applying key concepts like orbital stability. This highlights the potential of handheld VR-based informal learning programs to facilitate social learning, particularly by encouraging active verbalization and communication among participants.

4.3 Emotional Engagement

Emotional engagement was measured through participants' observed reactions, such as physical and verbal behaviors, focusing on expressions of positive or negative affect. Positive emotions were most prominently observed in scenes featuring visible, moving planets, including *Visible Solar System* (49% of scene duration) and *Planet Simulation* (59%). One notable observation of positive reactions, consistent across most groups, occurred during the transition from *True-Scale Solar System* to *Visible Solar System*. In this transition, planets that were initially represented only by blue arrows became visible and enlarged, resembling the familiar depiction of the solar system. Participants expressed excitement and surprise upon seeing the planets, often exclaiming, "Wow!", "Oh my gosh, I see planets!" (Group 2), or "Oh my god, I am so close to the Sun!" (Group 6). Positive emotions were also conveyed through nonverbal behaviors such as humming, laughter, and body movements like skipping, spinning, and running. These displays of excitement

often influenced others. For instance, in Group 3, one participant began spinning excitedly, prompting another participant to join in, sharing enjoyment of the experience. Similar expressions of positive emotions were observed during *Planet Simulation*. Participants frequently accompanied their verbal comments with excitement and happiness, especially when discussing their custom planets. For example, in Group 9, a participant exclaimed, “*Oh, where is mine? There’s mine! Mine’s huge!*” as soon as the simulation began. Participants were also enthusiastic about showcasing their planets to others. In Group 11, one participant repeatedly expressed excitement about his creation, saying, “*Oh, my planet! I love my planet! So cool, purplish! This is my purple planet! Look at my purple planet!*” This enthusiasm highlighted how creating their own planets fostered individual pride and shared enjoyment. Overall, visually dynamic and interactive scenes, particularly those featuring familiar visual representations or personal creations, elicited strong positive emotional engagement. This highlights the potential of handheld VR-based informal learning programs to amplify excitement and joy through shared experiences, enhancing the collective enthusiasm and engagement within the group.

4.4 Social Engagement

Social engagement measured behaviors involving interaction between participants or with the docent. Interpersonal communication and cooperative behaviors were most prominent during *Planet Simulation* (30% of its scene duration), while other scenes showed lower levels: *Moon Phase* (10%), *Visible Solar System* (9%), *Planet Builder* (8%), *Tides* (1%), and *True-Scale Solar System* (0%). During *Planet Simulation*, interactions often revolved around participants sharing excitement about their planets. These included encouraging others to view their creations (e.g., “*Look at my planet!*”), explaining their design choices (e.g., “*Mine was high velocity and very far!*”), or commenting on another participant’s planet (e.g., “*Yours is huge.*”). Such verbal exchanges frequently led to cooperative behaviors, such as jointly finding or exploring planets. For example, during *Visible Solar System*, a participant in Group 1 struggled to locate Mercury and verbalized, “*Where is Mercury?*” without addressing anyone specifically. Another participant who had already found Mercury responded, “*Mercury is right here!*” This led to both participants gathering around the planet, exploring it together. Participants often glanced at others’ tablets, which frequently sparked conversations. For instance, during *Planet Simulation*, a participant in Group 4 pointed at another participant’s tablet, expressing curiosity about what was displayed. This interaction quickly evolved into mutual sharing, where participants showed their custom planets and engaged in broader conversations. Participants also shared their planet creations with adults, such as summer camp teachers or parents. Another notable aspect of social engagement was participants mimicking each other’s behaviors. For example, in Group 5, when one participant began poking a planet, others quickly followed, poking the planets in front of them. Similarly, in Group 2, when a participant tilted his tablet at an extreme angle to explore a different perspective, another participant mimicked the action to see what her tablet displayed. Overall, social engagement was strongest in *Planet Simulation*, as it showcased participants’ creative

input, serving as an effective conversation starter even among participants who were nearly strangers. This highlights the potential of handheld VR-based informal learning programs to encourage interpersonal interactions by allowing participants to observe both each other’s behaviors and what others are engaging with on their devices.

5 Discussion

In the current study, we aimed to investigate the potential of handheld VR-based informal learning program to foster engagement across multiple dimensions—physical, intellectual, emotional, and social. Physically, scenes with a room-scale, dynamic content encouraged higher levels of active engagement compared to screen-based activities. Prior research underscores the importance of physical engagement in enhancing children’s cognitive functions [4] and learning outcomes [10]. Additionally, providing open learning spaces and the freedom to move supports student-centered and self-directed learning [22, 27, 35]. Intellectual and emotional engagements showed a similar pattern, where visually dynamic scenes, especially those involving personal creations, elicited active knowledge sharing, as well as strong positive emotions, that amplified excitement in group settings. Knowledge sharing is a critical aspect in learning, as verbal recitation engages the phonological loop, improving memory performance [1]. Furthermore, sharing and self-explaining knowledge, key elements of constructive learning, have been shown to promote better knowledge retention and application [6]. Positive emotions can also foster an atmosphere for active participation [25, 42] as well as enhance cognitive flexibility, as suggested by the broaden-and-build theory [13]. Social engagement was strongest during *Planet Simulation*, where participants’ creative input sparked conversations and facilitated interactions, even among those who were initially unfamiliar with one another. Prior studies have highlighted the critical role of interpersonal communication, such as peer discussions and collaborative learning, in fostering diverse perspectives and deeper understanding [24, 43]. Additionally, social connections build a sense of belonging, which is linked to academic success, persistence, and mental well-being [18]. The creative activities in *Planet Builder* and its extended experience during *Planet Simulator* were particularly effective in driving engagement. These scenes allowed participants to design and simulate their own planets, fostering a sense of ownership that naturally led to enthusiastic sharing and discussion [40].

Based on our observations from the *Solar System Explorer*, we propose the following design guidelines for developing effective handheld VR-based informal learning experiences to foster learner engagement: (1) incorporate room-scale content with dynamic elements to encourage active movement and exploration to enhance physical engagement and self-directed learning; (2) integrate visually rich, interactive scenes to promote intellectual engagement through knowledge sharing; (3) include elements that evoke positive emotions, such as personal creation or dynamic and familiar visual representations, to foster enthusiasm and connection; and (4) design opportunities for collaborative exploration and social interaction by encouraging participants to observe and engage with each other’s behaviors. By adopting these guidelines, future systems can harness handheld VR’s potential to create engaging, inclusive, and

impactful informal learning experiences. These insights contribute to the growing body of research on immersive technologies in education by identifying design elements that enhance multidimensional engagement in group-based learning contexts. Furthermore, they invite future research to explore how handheld VR can integrate collaborative and personalized learning experiences, along with its scalability and long-term impact on diverse learning environments.

6 Conclusion and Future Work

This study represents an effort to explore the application of handheld virtual reality in informal learning settings, highlighting its potential to offer shared and inclusive experience for diverse user groups. Building on this work, the project is currently transitioning to a web-based platform to reduce setup requirements and operational complexity. Unlike the current VIVE Pro 2 system with base stations and tracker-equipped tablets, the new version will use only tablets that connect to a shared virtual environment by scanning a QR code. This streamlined approach minimizes setup time and equipment demands, making it more practical for permanent museum installations and broader outreach events. In summary, this research underscores the potential of handheld VR in informal learning settings and lays the groundwork for future advancements in designing engaging and accessible educational experiences.

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