An Asymmetric Multiplayer Learning Environment for Room-Scale Virtual Reality and a Handheld Device

MICHAEL HOLLY, Graz University of Technology, Austria
SEBASTIAN RESCH, Graz University of Technology, Austria
JOHANNA PIRKER, Ludwig-Maximilians-Universität München, Germany
and Graz University of Technology, Austria

Many different digital learning environments are currently in use. In combination with virtual reality (VR) technologies, these allow the creation of engaging hands-on experiences. While VR environments can deeply immerse the person wearing the headset, spectators are often not actively involved or are not even considered in the design phase. This is an issue for learning environments, as learning often takes place in pairs or groups. We propose a novel system that enables more than one person to join the VR world in a co-located space to overcome this problem. In addition to the classic VR headset, the asymmetric VR system features a position-tracked tablet. To evaluate this asymmetric VR concept, we conducted a study with 14 students to explore the user experience and motivation, the social presence, and possible further fields of application. The results indicate that users in both perspectives feel that they can control the virtual world.

CCS Concepts: • **Human-centered computing → Ubiquitous and mobile computing**; • **Applied computing → Interactive learning environments**; **Collaborative learning**.

Additional Key Words and Phrases: STEM education, virtual reality, asymmetric multiplayer, collaborative learning

ACM Reference Format:
Michael Holly, Sebastian Resch, and Johanna Pirker. 2023. An Asymmetric Multiplayer Learning Environment for Room-Scale Virtual Reality and a Handheld Device. *Proc. ACM Hum.-Comput. Interact.* 7, MHCI, Article 197 (September 2023), 19 pages. https://doi.org/10.1145/3604244

1 INTRODUCTION

The dropout rate of students in STEM (science, technology, engineering, and mathematics) fields is a major challenge in Western education systems [7]. While graduates in these fields of study are of great importance to the economy, a very high number of students are not motivated to complete their degree programs [28]. In recent years, immersive virtual reality (VR) environments and also game-based strategies have been explored as a potential solution to this problem. Design strategies from games in particular have been shown to be a valuable tool for learning in an engaging way and players do not mind spending time finding out the best way to solve the puzzles in games [30].

In addition, many games utilize immersive virtual reality hardware to capture the focus of the player. In recent years, such hardware has become readily available and affordable for consumers. VR environments can make the user feel like they are physically present in the virtual world through head- and hand-tracking [42]. In a learning context, added benefits of VR are that abstract

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Authors' addresses: Michael Holly, Graz University of Technology, Graz, Styria, Austria, A-8010, michael.holly@tugraz.at; Sebastian Resch, Graz University of Technology, Graz, Styria, Austria, A-8010, sebastian.resch@tugraz.at; Johanna Pirker, johanna.pirker@tugraz.at, Ludwig-Maximilians-Universität München, Munich, Bavaria, Germany
, D-80539 and Graz University of Technology, Graz, Styria, Austria, A-8010.

2573-0142/2023/9-ART197
https://doi.org/10.1145/3604244

phenomena and concepts can be visualized. Learners can physically explore objects which are not accessible in real life, and experiments that are dangerous or time-consuming to conduct in the physical world can be done in a safe and fast manner [12, 38].

Since VR applications try to create a high degree of immersion for a single user, the spectators are often not considered in the design of the interactions [43]. Additionally, in our previous experience (blinded for review) with the design of educational VR experiences, we noticed many potential flaw backs.

Educational VR experiences often require a significant amount of space, and individual setups can be costly, which means that not all students can learn simultaneously. The process can be time-consuming, and more importantly, the learning experience can become one-sided. However, asymmetric experiences provide an opportunity for learners to collaborate and work together on their learning experiences, as many pedagogical models suggest. The proposed asymmetric VR multiplayer application allows a handheld user to participate in a VR environment through a tablet and interact with the virtual world from a different perspective, which encourages learners to work together. This approach also offers the added benefit of sharing setups and making them more accessible to all students, reducing costs and enhancing the practicality of VR in education. By promoting collaboration and shared learning experiences, the proposed application has the potential to enhance engagement, motivation, and learning outcomes. Social presence in virtual reality can be experienced both with other players who are physically present in the same physical location as the user, as well as with other players who are located remotely. When engaging with other players who are physically present, social presence can be enhanced through the use of shared physical spaces, such as virtual reality arcades or gaming lounges, that provide a sense of community and shared experience [33].

To design an asymmetric learning experience for interactive environments, we can also learn from successful game design projects. Games like “Keep Talking and Nobody Explodes”[1] show how the interactions can be deliberately designed to incorporate more than one player into a virtual world in a collaborative way.

As mobile devices are an increasingly popular and important medium for education, providing accessibility and flexibility, we propose a combination of VR experiences together with handheld mobile devices allowing learners to participate in the learning experience in an interactive and flexible way. By enabling a handheld user to participate in the VR environment through a tablet, the study expands the possibilities of mobile learning and provides a more interactive and immersive learning experience.

A possible use case for the application of asymmetric VR multiplayer technology in education would be solving a complex problem or task that requires collaboration among students. In this scenario, it is assumed that one student needs to solve an assignment in VR that consists of multiple parts. However, the other two students have access to different information that is needed to solve the problem. Therefore, the students need to help each other and share their knowledge to solve the assignment together.

The student in VR is placed in a virtual environment where they need to solve the problem. The other two students have a tablet computer and can view the virtual environment from different perspectives and share information that helps the student in VR to solve the problem. By collaborating, not only are learning outcomes improved, but social skills such as communication, teamwork, and empathy are also fostered. The use of VR technology in this type of learning environment provides an interactive and immersive learning environment that motivates students and promotes effective learning.

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[1] https://keeptalkinggame.com

Utilizing VR for teaching and learning purposes has been explored in recent years [32, 37]. However, the use of collaborative multiplayer elements in VR for learning purposes has not been explored in detail. This is despite the fact that there are concepts in education, such as collaborative learning, that could potentially be applied effectively in a multiplayer learning application [24].

In this paper, we propose an asymmetric VR multiplayer application that is inspired by VR learning environments, multiplayer concepts from video games, and collaborative learning. As asymmetric VR experiences are a still an underexplored topic in literature, we want to understand its potential better with a focus on studying the potential to enhance engagement, motivation, and learning outcomes, as learners are able to share knowledge and solve problems together.

The main research objectives are defined as:

- Investigate how dominance differs between two asymmetric users (VR user, handheld user) and if one of the two users takes a more dominant role or feels more in control.
- Compare the social presence of the two users from different points of view based on the interaction and visualization of the two users.
- Examine the learning experience and motivation of the users and analyze if there are differences when interacting with the same virtual world through different perspectives.
- Verify if the users' ability to answer questions regarding the learning content improves after interacting with the system.

Contribution. In this paper, we present an AB split user study with 14 students, discussing an asymmetric multiplayer learning environment for room-scale VR and a handheld mobile device. The system allows an additional user to participate in a VR environment through a tablet. The position of the tablet in the physical space is tracked and allows the user to inspect the virtual world from different perspectives. In addition, the touch screen can be used to influence the virtual world. We demonstrate the performance of the system based on the implementation of a concrete learning use case. The learning content of the experiment is digital color. The experiment tasks require players to work together and communicate with each other. The system is evaluated in terms of the experience and motivation of the users, the social presence of the two perspectives, the feeling of being in control, and the learning content. Furthermore, additional experiments suitable for such setups and other possible fields of application are explored.

2 BACKGROUND AND RELATED WORK

2.1 Teaching and Learning

In recent years, it has become necessary to rethink the traditional teaching approach. As a consequence, many digital variants have been tried out. This has revealed many difficulties and opportunities [31, 45]. Digital learning encompasses different settings, technologies, and concepts. Tools and infrastructure used for digital learning include learning platforms, digital media, mobile devices, network technology, and the internet [23]. Technology can be used to enhance conventional synchronous teaching methods, but it can also support flipped classroom approaches, where students prepare and study for a class autonomously [40]. The benefits of digital learning include location independence [3], a flexible schedule [11], and a positive effect on student motivation [27]. However, the mode and manner in which digital learning tools are utilized matters as well. For example, in a distance learning setting employed during the COVID-19 pandemic students showed a lack of motivation [45]. It is important to actively shape the educational experience and consider the way students communicate, interact and collaborate with each other [10, 29].

Collaborative learning (CL) and computer-supported collaborative learning (CSCL) are educational approaches that consider multiple students working together. They encourage learners to ask questions, justify their opinions, and explain their reasoning. CSCL focuses on how digital tools can support such learning activities [44]. A CL environment typically consists of the following elements: (1) positive interdependence, meaning that group members rely on one another to complete a task; (2) considerable interaction, where members help and encourage each other; (3) personal responsibility, meaning that each member is held accountable; (4) social skills, in the sense that learners practice communication and decision-making; and (5) group self-evaluating, meaning that members set group goals and evaluate their progress towards them as a group [24]. CSCL utilizes different technologies to create these elements. These can be online videos or learning platforms, but also dynamic technologies such as simulations, games, or immersive technologies [21].

2.2 Virtual Reality Learning Environments

The use of game elements in non-game settings (e.g. marketing) has been common in many domains and is known as gamification [26]. In an educational setting, this topic can be approached from two sides. Game elements can be added to learning environments or learning content can be added to games. Gamification, which involves incorporating game design elements in non-game contexts, can be introduced at different levels. Serious games, on the other hand, are full-fledged games designed primarily for education, training, or conveying information. The transition between gamification and serious games is gradual [9]. Some topics lend themselves to be taught via game-based approaches. In STEM fields specific concepts can be visualized and interactive simulations can be used to make physical phenomena tangible [34]. In addition to interactivity, immersion may influence the learning rate of students. Virtual laboratories offer a safe and cost-effective alternative to traditional learning methods and experiment setups [47]. One way to achieve a high degree of immersion is the use of VR technology [6]. Research has shown that VR learning environments can be a benefit for the learning process and even score better in factors that influence learning activities in comparison to a flat-screen variant [38]. However, challenges such as motion sickness, interface design [5], and acclimating students to the new technology [46] need to be addressed. VR experiences need to be designed for users in such a way that they actively interact with the virtual world, and that both theoretical information and tasks must be available during the learning experience to guide users through the experiment [1, 41]. The optimization of the knowledge acquisition process remains one of the most challenging aspects of VR learning experiences [5]. As highlighted by Pirker et al. [36], there is a need for collaboration among students in virtual reality. Teachers identified only one person being immersed as a potential issue if VR is used in a group setting [35].

2.3 Asymmetric Multiplayer

This can be overcome by drawing inspiration from multiplayer game design, where more than one player is considered. In particular, the asymmetric game design allows a deliberate shaping of the players' interaction on the levels of mechanics, dynamics, and aesthetics [15]. In a similar way to collaborative learning, the concepts of cooperation and interdependence also apply to asymmetric games [8]. The benefits this type of game design brings include allowing players of different skill levels to play together, strengthening teamwork, fostering critical thinking through knowledge asymmetry, and furthermore assuring a positive impact on the player experience [22, 25, 43].

2.4 Application in Games and Research

The combination of asymmetric game design concepts and VR technology is already in use in games and in research. In the VR version of *Keep Talking and Nobody Explodes*[2] one player needs to defuse a Bomb in VR by solving puzzles, while the other co-located players use a printout

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[2] https://keeptalkinggame.com

“bomb defusal manual” to give instructions on how the riddles can be solved. In the academic domain, various projects explore the application of asymmetric concepts for games, training, and learning applications using custom prototypes. They encompass the use of desktop computers [18], projectors [20], additional displays mounted to the VR user’s head or controllers [13, 14], and tablets [43] to create a view that allows players without a headset to participate in the experience.

3 LEARNING APPLICATION

For implementing the learning application, we investigated a pre-build laboratory environment supporting multiple interactive and engaging learning methods. The lab itself allows the creation of different learning content for desktop, web as well as VR [17]. However, it does not support multiple users joining the VR experiments. There is also no opportunity for conventional PC users to collaborate with VR users. Therefore, we used the laboratory environment as inspiration and starting point to create and explore a new approach to asymmetrically engage non-VR users in a VR environment.

3.1 Initial Requirements

Based on our previous work (blinded for review) we identified the following requirements for the learning application framework and the use case allowing experiencing learning content in an asymmetric and collaborative way. Two users should be able to join a virtual world. One via a virtual reality headset (VR user), and the other using a tablet (handheld user). The following list defines the initial requirements for the framework (F) and the implemented use case (U):

- F1: The VR user can interact with an environment in virtual reality and is aware of the handheld user, while the handheld user can move a tablet in the physical space to join the virtual world and see the whereabouts of the VR user (“window into the virtual world”). Both users should be able to influence the virtual world.
- F2: Inputs from the VR controllers, as well as the touch screen of the tablet, should be taken into account.
- F3: The setup in the co-located space should be designed to allow both users to communicate by simply talking to each other.
- U1: The use case should take interdependence and communication between the users into account in order to shape a collaborative experience.
- U2: The VR user can directly interact with the learning content. The handheld user should provide guidance to the VR user, while still being able to influence the virtual world.
- U3: The usability and experiment scope of the application should allow the users to get started quickly.

3.2 Framework Setup

We implemented a framework that supports the creation of an asymmetric VR multiplayer experience. While the learning application currently comes with one implemented use case, it is possible to port the functionality for other learning contents. The framework is implemented in Unity[3] 2020 LTS using the Universal Render Pipeline and the SteamVR[4] plugin for Unity. The features are built for Valve’s room-scale tracking system using base stations to track the headset, controls, and other trackable devices. In this setup both users are located in the same room to allow the tracking of all devices via one base station pair. To run the experience, the following hardware components are required:

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[3] https://unity.com

[4] https://steamcommunity.com/steamvr

- A gaming PC capable of rendering the view for the VR and handheld user simultaneously.
- Two VR base stations for room-scale tracking.
- A VR headset compatible with Valve's room-scale tracking system ("Lighthouse Tracking") and two corresponding controllers.
- A tablet capable of running a modern mobile web browser.
- An HTC Vive tracker for tracking the tablet.
- A wireless network router.

Figure 1 shows how the individual components interact with each other. The system does not rely on classic networking as commonly used in multiplayer games. Instead, both views are processed on a desktop gaming PC. Based on the Unity Render Streaming package[5] the view for the handheld user is streamed to the tablet through a WiFi connection. In addition, the inputs of the handheld user are transmitted to the PC and handled there. This setup enables the straightforward operation of the system since no software needs to be installed on the tablet. In order to get the position of the tablet in the physical space an HTC Vive tracker is mounted to the back or top of the device.

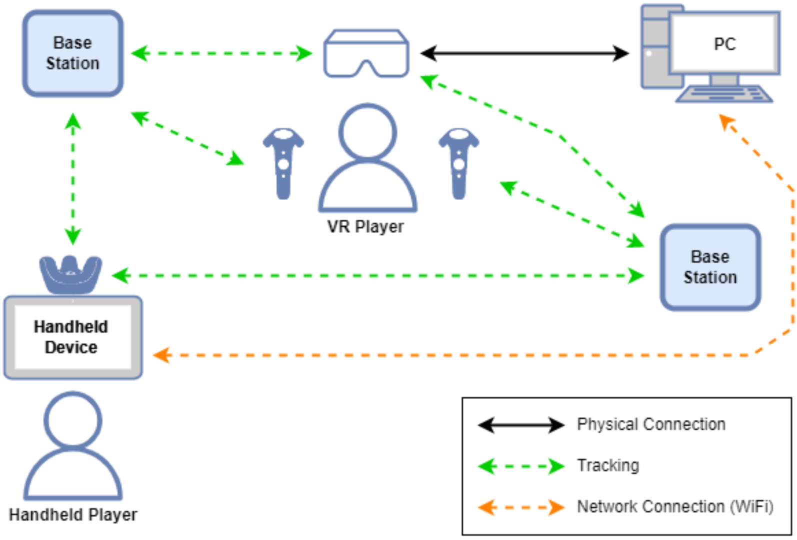

Fig. 1. Interaction of components for the asymmetric VR framework.

The framework provides a basic structure for the implementation of different learning applications. However, the features are implemented within one VR and another handheld prefab, which can be imported and adapted to other use cases. The framework comes with a working configuration for tracking and streaming, models and avatars for tracked objects and the users, and a selection of UI components for the handheld user, including settings for the system as well as space for use-case-specific elements.

4 USE CASE

In order to test and experience the features, we implemented a specific learning use case about digital color and the RGB color model. The tasks given to the users through on-screen instructions

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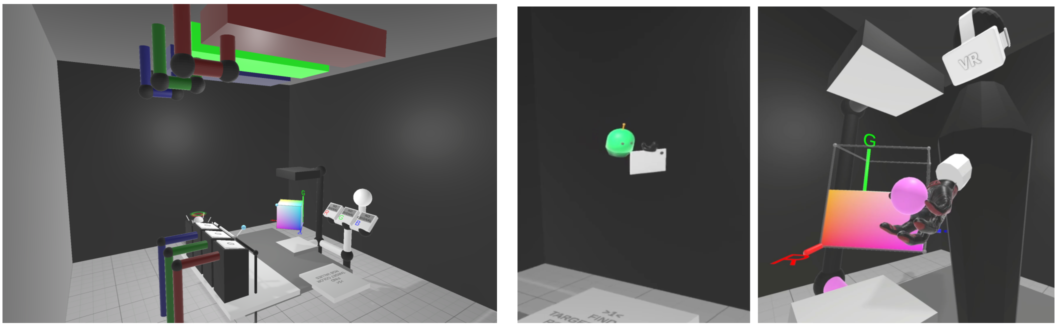
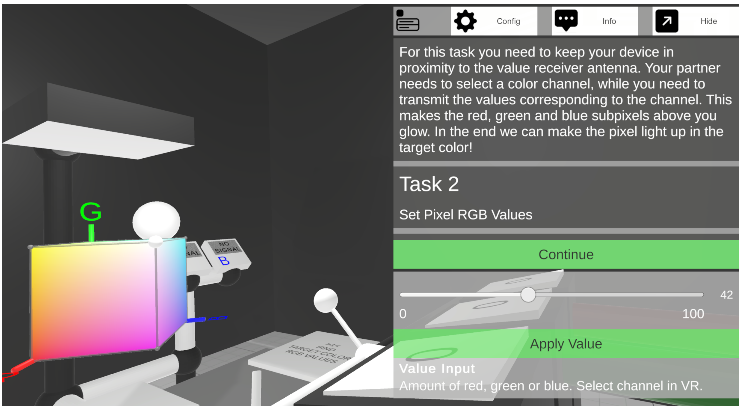
[5] https://docs.unity3d.com/Packages/com.unity.renderstreaming@3.1/manual/index.html

are to find the RGB color values based on a given color, then make a stylized pixel light up in the correct color according to these values. The tasks incorporate interdependence by splitting the information necessary to complete them between both users. Figure 2c illustrates the handheld user interface. The experience requires both users to communicate and work together in order to reach completion. To find the RGB color values the handheld user needs to compare two colors while the VR user manipulates one of them using an interactive RGB color cube. After that, the resulting values are only visible to the VR user but need to be entered by the handheld user. Various objects are part of this use case, including a color value display, a station to switch between color channels in VR, and hints and displays for the handheld user. Table 1 describes the main experiment object of the experiment that the players need to interact with in order to fulfill the tasks. Figure 2a shows how the objects are embedded in a 3D environment representing the inside of a pixel. How the users can see each other within the virtual world is shown in Figure 2b.



(a) 3D environment containing decorative and interactable objects.

(b) Avatars as they are seen by the respective other user in the virtual world.



For this task you need to keep your device in proximity to the value receiver antenna. Your partner needs to select a color channel, while you need to transmit the values corresponding to the channel. This makes the red, green and blue subpixels above you glow. In the end we can make the pixel light up in the target color!

Task 2

Set Pixel RGB Values

Continue

Apply Value

Value Input

Amount of red, green or blue. Select channel in VR.

(c) Screenshot of the handheld player's user interface. The top row contains buttons that open and close different panels. The currently opened panel provides an area for use case implementations to show hints for the currently active task. The handheld player prefab is aware of its position relative to objects in the environment and can show additional elements underneath the hints panel when close to a certain object.

Fig. 2. The asymmetric multiplayer learning environment

Table 1. Experiment objects and interactions which are part of the experiment.

Item	Description
Target Color Display	Visible to the handheld player. Shows the color that should be generated, but does not give information about its RGB values.
RGB Color Model	Visible to both players. A visualization of the RGB color model in the form of a cube. Allows the VR player to interact in order to inspect different colors.
RGB Value Display	Visible to the VR player. Shows the RGB values of a color that was selected using the *RGB Color Model*.
RGB Channel Switch	Visible to both players. An interactive object that allows the VR player to direct a value toward the red, green, or blue color channel.
Channel Value Input	Visible to the handheld player. An input that allows to set the value for one of the RGB channels which was selected using the *RGB Channel Switch*.
Display	Visible to both players. A visualization that shows the RGB subpixels (similar to a magnification of an OLED or LCD display). The brightness corresponds to the values set by the *RGB Channel Switch* and *Channel Value Input*

5 EVALUATION

In previous studies, we focused on engagement, usability, and user experience of different learning experiences including room-scale VR, mobile VR, and traditional desktop applications. The study results indicated room-scale VR as the most engaging and immersive learning form [blinded Ref]. However, we did not explore collaborative multiplayer elements in VR. Therefore, the focus of this study was on the social presence from the two different perspectives in an asymmetric VR learning environment, as well as on the motivation, learning experience, and outcome. Furthermore, the goal of the study was also to investigate the different levels of dominance between the two asymmetric users (VR user vs. handheld user) and to identify which user feels more in control. To compare the distinct experiences, we conducted an AB split-user study with 14 participants from a local educational institution.

5.1 Material and Setup

To perform the study, we used a gaming PC with a high-performance graphic for rendering the virtual world and streaming it to the handheld device. For the VR setup, we used an HTC Vive headset, two controllers, and an HTC Vive tracker V3.0 compatible with Valve's Lighthouse 2.0 tracking system running SteamVR. Since the rendering process of the handheld players is processed on the high-performance PC, the handheld device does not require to have a powerful graphic unit. Therefore, we used an Android 12 tablet (Samsung Galaxy Tab S6 Lite with a 10.4" display) as a handheld device. For the networking connection, we chose a tp-link Archer MR200 WiFi router. To prevent cheating, we covered the PC screen so that the handheld user could not see the VR user's view. Figure 3 shows three different options for mounting the tracker. We used the option with the tracker on the top edge, which gives the best tracking results. The setup itself was located in a single room where the participants had a play area of 3m x 3m.

Fig. 3. A tablet with the tracker mounted to different positions. The tracker position in the far left image provides the best visibility for the base stations. The far right configuration adds the least weight to the handheld device. The middle image shows a compromise between the other two configurations.

5.2 Method and Procedure

To conduct the study, we recruited 14 students from a local educational institution. The participants were randomly assigned into groups of two. Each group consisted of one VR user and one handheld user. After assigning them to groups, we asked them to fill out a pre-questionnaire. It included several questions about general personal information such as visual impairments, prior experience with computer usage, video games, virtual reality, art and drawing, creative software, and e-learning tools rated on a Likert scale between 1 (strongly disagree) and 5 (strongly agree). The questionnaire also included a color vision test (Ishihara test[6]) to identify color deficiencies. This allowed us to detect possible issues with the VR color experiment. To assess the learning outcome, we asked the participants the same knowledge questions before starting the experiment and also at the end of the experiment. We asked them four multiple-choice knowledge questions regarding pixels and sub-pixels, color models, color channels, and the representation and visualization of the RGB color model with exactly one correct answer. After completing the pre-questionnaire and the knowledge questions, participants were asked to perform the following tasks:

(1) Enter the virtual world using the VR headset and tablet and get familiar with the system works.
(2) Follow the on-screen instructions on the tablet and try to find out the RGB values of the target color using the interactive RGB color model visualization.
(3) Apply the identified color values to the pixel. Hints are given by the handheld device.
(4) Observe whether the pixel lights up in the correct color or not. Otherwise, go back and refine the value.

For the tasks, a random color was shown to the handheld user. Both users had to work together to find out the correct RGB value for the color displayed on the tablet. The users had to redo the tasks until they entered the correct values for the given color. After fulfilling the tasks, we asked the participant to fill out a post-questionnaire where the users had to define the used device and rate their experience during the experiment. The post-questionnaire was designed using several standardized questionnaires to ensure reliable and accurate data collection. To measure the emotional response of the users, we used the Self-Assessment Manikin (SAM) questionnaire including three series of images with five pictures [4]. Participants rated the three categories valence (from “pleasant” to “unpleasant”), arousal (from “excited” to “calm”), and dominance (from “not in my control” to “in my control”) by selecting the best-representing image or a score between two images, giving a 9-point scale. The Questionnaire on Current Motivation (QCM) [39] was

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[6] https://www.colorblindnesstest.org/ishihara-test/

used to get information about the current learning motivation divided into four scales: Fear of failure, interest, probability of success, and challenge. Users were asked to rate them on a Likert scale between 1 (fully disagree) and 7 (fully agree). To compare the social presence of the VR and handheld player, we choose the social presence module of the game experience questionnaire (GEQ) [19]. The items are specifically designed to measure the psychological and behavioral involvement with other social entities on a range between 0 (not at all) and 4 (extremely). For the learning experience, we used the Player Experience Inventory (PXI) questionnaire including ten categories with three sub-statements rated on a Likert scale between -3 (strongly disagree) and 3 (strongly agree) [2]. Half of the items focus on the functional aspects of the experience, and the others on the psychosocial level.

After the first test run, the two users were instructed to swap their roles to redo the experiment from the other perspective including the same post-questionnaire (SAM, QCM, GEQ, PXI) at the end. Finally, participants rated their personal preferences on the used devices (VR or tablet) and whether they would like to use the system with peers or teachers. We asked them also a few general open questions for feedback and the same knowledge questions to assess their learning outcome.

5.3 Participants

To conduct the study we recruited participants (students, employees, and interns) from a local education institution to select a wide user range. 14 participants were willing to take part on-site. The participants were not expected to have any prior knowledge about the learning content. Due to invalid entries in the data, one group was excluded from the data. The excluded outliers deviate significantly from the rest of the data and would thus have a strong impact on both the results and the conclusion. The responses were thus excluded from the evaluation resulting in 12 data records for both VR and the handheld perspective. The participants (5 male, 7 female) were aged between 15 and 32 (AVG=20.00, SD=5.80). Four participants reported having visual impairments (glasses or contact lenses) and one participant was experiencing slight color blindness in the color vision test. However, all participants were able to manage both the VR experience and the given tasks. The participants rated themselves as being relatively experienced with computers (AVG=3.75, SD=0.75) and stated that they were not experts in color theory or in working with digital color (AVG=2.33, SD=1.07). While some of the participants already had experience with VR, others were less familiar with its usage (AVG=3.08, SD=1.24). Figure 4 gives an overview of the expertise the participants have in the different fields.

6 RESULTS

The following section presents the results focusing on emotional responses like pleasure, arousal, and dominance. Furthermore, users' motivation and learning experience during the learning process are investigated and the learning outcomes are examined after the learning application.

6.1 Reactions on Valence, Arousal, and Dominance

To measure the categories valence, arousal, and dominance, we asked the participants to rate their emotional responses on a 9-point scale. In the valence domain, most participants had a positive experience when using VR (AVG=2.17, SD=1.95) and the handheld device (AVG=2.58, SD=1.38). For the arousal category, users rated the VR perspective as neutral (AVG=5.50, SD=2.58). In comparison, the handheld perspective was rated moderately higher (AVG=6.00, SD=1.95). However, the individual users ranked the VR perspective with higher variability. Nevertheless, VR users scored the dominance almost identical compared to the handheld users (VR: AVG=7.17, SD=170; Tablet: AVG=7.17, SD=1.53). Figure 5 shows the results of the SAM questionnaire for the VR and handheld perspective on a scale from 1 to 9.

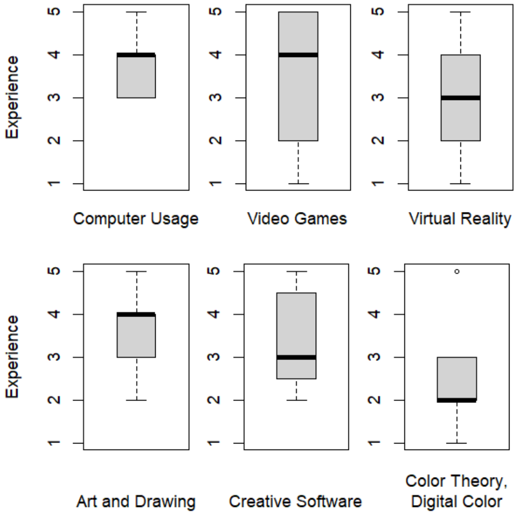

Fig. 4. Box plots showing the experience/expertise of participants in different fields related to the learning environment and content on a scale from 1 (strongly disagree) to 5 (strongly agree).

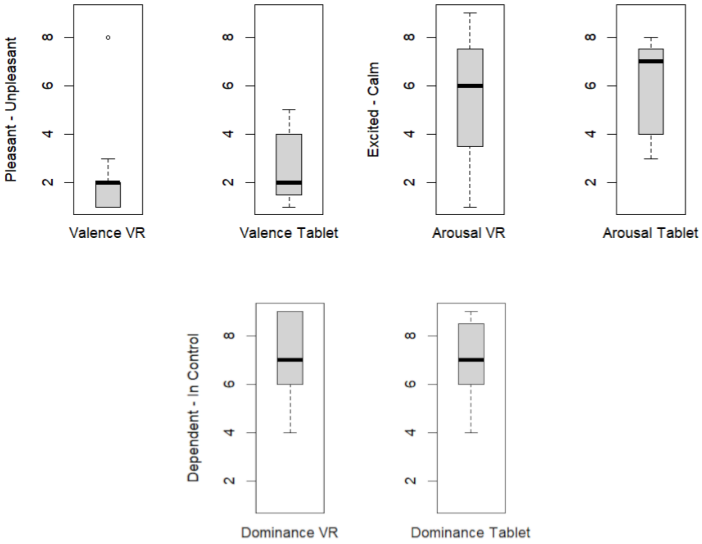

Fig. 5. Box plots showing the SAM questionnaire results in the valence, arousal, and dominance domain for the VR and tablet perspective on a scale from 1 to 9.

6.2 Social Presence

Table 2 shows the result of the social presence module of the game experience questionnaire in terms of psychological and behavioral involvement with the other user. The element *Psychological Involvement - Empathy* involves the feeling of empathy, connectedness, and admiration directed towards the other user. According to these findings, the results indicate that VR users are empathetic when collaborating with handheld users and vice versa. Furthermore, the results indicate that users had either no negative emotions toward the other user, or only minimal ones. These include negative feelings such as jealousy, revenge, schadenfreude, and the influence of the other user's mood. The *Behavioral Involvement* element covers the reliance and attention directed by the users to the other user. Furthermore, it inquires into how the behavior of a user affects the other user. The level of behavioral involvement was rather given a relatively high ranking for both user perspectives, with a moderately higher rate for the VR perspective.

Table 2. Results of the Game Experience Questionnaire: Social Presence on Likert scale between 0 (not at all) and 4 (extremely)

	VR		Tablet	
Component	AVG	SD	AVG	SD
Psychological Involvement (Empathy)	3.19	0.90	3.15	0.82
Psychological Involvement (Negative Feelings)	1.07	1.45	0.98	1.38
Behavioral Involvement	3.46	0.75	3.29	0.81

6.3 Learning Experience and Motivation

To understand how users experience the different perspectives in the learning and motivation contexts, we asked each participant to rate their experience on a 7-point Likert scale from -3 (strongly disagree) to +3 (strongly agree) using the PXI questionnaire. Table 3 presents the results of the different PXI categories. Each category consists of three sub-statements where we used the average as an indicator for the respective category. The results indicated high levels of curiosity, audiovisual appeal, and clarity of goals. This is in line with the positive rating of the valence dimension from the SAM questionnaire. Overall, VR users rated the ease of control higher than handheld users. Users differ most significantly on the statement "It was easy to know how to perform actions in the experience." (Wilcoxon rank sum test: $p = 0.04$).

To explore users' motivation during the learning process, we ask participants to rate their current motivation on a 7-point Likert scale from 1 (fully disagree) to 7 (fully agree) using the QCM questionnaire. The results of the QCM are presented in Table 4. The outcomes indicate a low level of anxiety for both perspectives and a good probability of both success and interest. In addition, users rated the challenge level as moderate, which is evident in the PXI challenge results. There were no significant differences between the two user perspectives.

6.4 Correlations

In order to investigate the connections among the various questionnaire items, a correlation analysis was conducted. The resulting correlation matrix shows the correlation coefficients of the distinct variables and measures the strength and direction of the relationship ranging from -1 to +1. A correlation coefficient of zero suggests that there is no relationship between the variables. The colors displayed in the plotted matrix indicate the strength of the correlation: dark blue indicates a strong positive correlation, white indicates no correlation, and dark red represents a strong negative correlation. The correlation matrix for VR users among the various items is presented in Figure 6, while the correlation matrix for tablet users is shown in Figure 7. For VR users, there is a high correlation between dominance-probability of success (0.74), dominance-autonomy (0.85), probability of success-ease of control (0.78), interest-curiosity (0.75), meaning-mastery

Table 3. Results of the Player Experience Inventory on a Likert Scale between -3 (strongly disagree) and 3 (strongly agree).

	VR		Tablet	
Category	AVG	SD	AVG	SD
Meaning	1.61	1.23	1.50	0.85
Curiosity	2.19	0.62	2.14	0.83
Mastery	1.92	1.18	1.69	1.51
Autonomy	1.89	0.98	1.42	1.44
Immersion	1.86	1.42	1.28	1.77
Progress Feedback	1.08	1.42	1.36	1.15
Audiovisual Appeal	2.22	0.93	2.14	0.99
Challenge	1.14	1.64	0.92	1.75
Ease of Control	2.31	0.79	1.81	1.19
Clarity of Goals	2.08	0.97	2.29	1.12
Enjoyment	2.50	0.56	2.42	0.60

Table 4. Results of the Current Motivation on a Likert Scale between 1 (fully disagree) and 7 (fully agree)

	VR		Tablet	
Category	AVG	SD	AVG	SD
Anxiety	2.17	1.74	2.82	2.02
Challenge	4.96	2.14	4.65	1.99
Probability of Success	6.04	1.18	5.65	1.69
Interest	5.79	1.41	5.98	1.19

(0.92), curiosity-autonomy (0.73), and progress feedback/ease of control (0.72). A strong negative correlation for VR users was detected between anxiety and mastery (-0.72). In contrast, tablet users showed a high correlation between the probability of success-mastery (0.74), empathy-immersion (0.86), mastery-autonomy (0.84), mastery-ease of control (0.74), and autonomy-ease of control (0.84). Negative correlations were detected between valence-mastery (-0.73), valence-ease of control (-0.82), anxiety-probability of success (-0.91), anxiety-mastery (-0.87), and anxiety-autonomy (-0.71).

6.5 Learning Outcomes

To evaluate the learning outcomes, we asked the participants four knowledge questions about pixels, color models, color channels, and the representation and visualization of the RGB color model. Before the experiment, 41.70% of the participants answered the knowledge questions correctly in the pre-questionnaire. After finishing the learning tasks of the application, 81.20% of the participants were able to answer the same questions correctly. To identify changes in proportion for the paired knowledge data, we used the McNemar's test. The test results indicated a significant improvement (p = 0.004) for the knowledge question regarding the visualization of the RGB color model.

6.6 Additional Findings and Comments

Finally, we requested feedback from the participants themselves on their preferences and ideas for enhancement. Issues mentioned by the participants included a strong preference for using

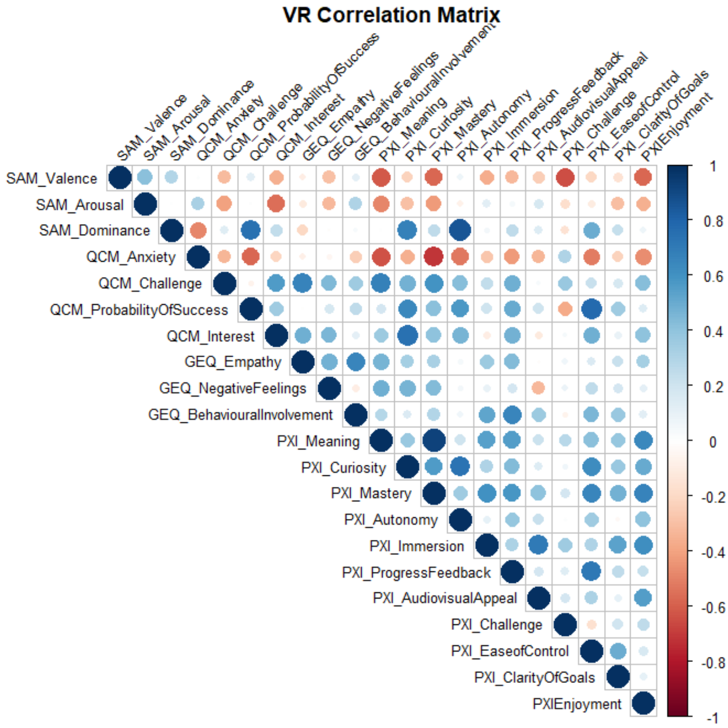

Fig. 6. Graphical representation of the VR correlation matrix showing the correlation coefficients between SAM, QCM, GEQ, and PXI questionnaire items.

an asymmetric multiplayer system for learning purposes either with peers or domain experts depending on individual preference. One person would prefer using it with peers, one with domain experts, while nine said would prefer to have both options. Only one participant did not indicate a preference. Furthermore, eight participants preferred using the VR headset, whereas four users preferred operating with the use of a handheld device. The participants also had some great ideas for potential new use cases for an asymmetric VR multiplayer environment of the kind they had experienced. For example, they suggested use cases for photography and building molecules from atoms.

7 DISCUSSION

The feedback and evaluation results of the asymmetric VR learning experience we received were overall very positive. Participants enjoyed the collaboration with the other user in the shared virtual environment and asked for the possibility of redoing the experiment with different colors. When comparing the two perspectives, it became evident that the handheld device can compete with VR in many aspects. While both approaches allow users to interact with the virtual world, they differ in how accurately these interactions are registered by the system. A few users preferred working with the tablet, while most participants indicated that they would rather enter the virtual world through a VR headset. This suggests that there is still room for use with traditional devices even in more immersive environments such as VR technologies. The results of the SAM questionnaire show that users in both perspectives felt that they could control and influence the virtual world. Neither of the two perspectives leads to a more dominant role during the experiment. This indicates that

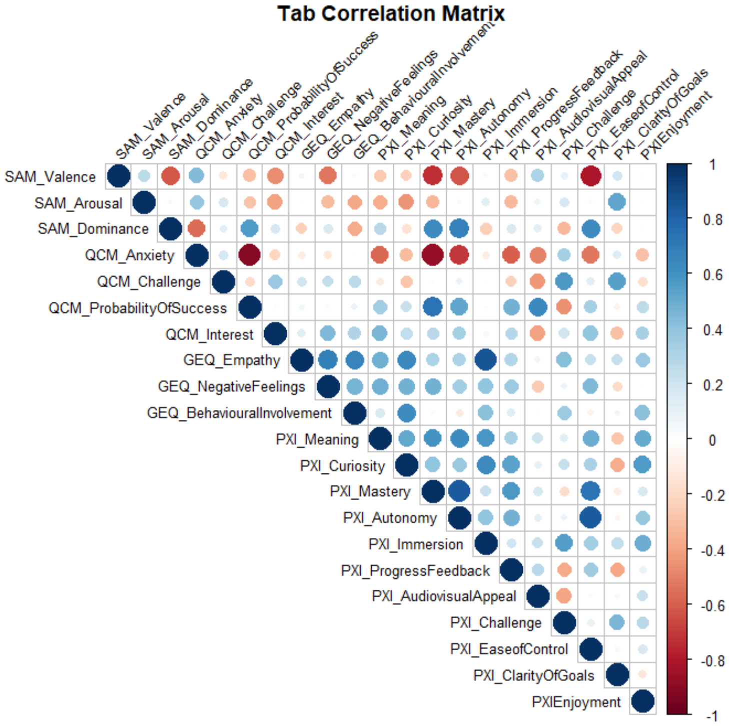

Fig. 7. Graphical representation of the Tab correlation matrix showing the correlation coefficients between SAM, QCM, GEQ, and PXI questionnaire items.

including interdependence from collaborative learning Hmelo-Silver et al. [16] and communication from asymmetric games like “Keep Talking and Nobody Explodes” can be beneficial for learning. The sense of control the participants have can be explained by the fact that they had to collaborate with each other to complete the tasks in the experiment successfully. Additionally, there was a higher dispersion within the arousal domain ratings for VR users; some felt excited while others felt calmer when using it. This variance may result from individual user preferences or experiences with the immersive virtual environment. It underscores the importance of considering user reactions when designing applications involving immersive technologies. In the social presence context, the findings indicate a positive psychological and behavioral involvement for both perspectives. The users were attentive to each other’s behavior, they felt empathy and had no negative feelings toward the other user. The possibility to interact virtually with each other was greatly appreciated by the users. While these results are encouraging, there is still room for improvement with regard to social presence. The participants requested more realistic characters through inverse kinematics or full-body tracking. Such enhancements would gap the physical differences between the two parties even further by providing a more lifelike experience overall. The positive findings from the SAM questionnaire regarding the valence domain, the low anxiety score in the QCM, and the high rating for enjoyment in the PXI indicate a positive and enjoyable experience for both VR and handheld perspectives. There were some outliers regarding ease of control for the handheld perspective, however, which might be due to its interaction design. It was intended for both users to have full access to virtual objects without having to teleport in the virtual environment. Users were able to physically move towards objects in order to interact as in real-life scenarios. Different correlations have been identified for VR users and tablet users. Specifically, VR users who rate their dominance as high may also have a higher level of motivation to succeed in the virtual environment. This could be because the feeling of control and power could lead to increased confidence and self-efficacy, which can motivate individuals to engage in and persist with challenging tasks. The correlation between the probability of success and ease of control could be due to the fact that feeling in control can increase the sense of self-efficacy and confidence the user experiences. Users who rate their dominance as high may also report higher levels of autonomy because they were able to feel more in control of their actions and decisions within the virtual environment. Furthermore, users with a higher level of interest tend to have a higher level of curiosity, as they may be more likely to explore the virtual environment and seek out new information and features. In contrast, tablet users who rated a high probability of success tend to have a higher level of mastery. This could be from the fact that they feel more confident and competent in their ability to navigate and control the virtual environment on a mobile device. Tablet users who felt higher levels of empathy for others tended to have higher levels of immersion, as they were more attuned to social cues and emotional states of virtual characters and felt more involved in the virtual world. As tablet users felt that the used mobile device is a suitable tool for controlling the virtual environment and that their actions have a clear and direct impact on the virtual world they tend to have a higher sense of autonomy. This could reflect the extent to which the user feels a sense of agency and control over their actions and decisions within the virtual environment. The negative correlation between anxiety and mastery for both user groups could be due to the fact that users with high anxiety have less confidence in their abilities to navigate and control the virtual environment. The use of a tracked tablet for specific use cases can be an innovative approach to improve the user experience. However, the interaction is not always intuitive or easy to understand how the device works, and what interactions are available through the touch screen. At the beginning of the experiment, several participants had a few troubles using the touch interface. It shows the importance of a well-interactive design for the combination of different input devices for virtual environments. The system has to provide clear instructions with ease-to-use navigation techniques. The positive audiovisual appeal construct in the PXI questionnaire indicates a good style, look and feel as well as aesthetics for the experience. Also, the verbal communication between the two users worked well. The learning outcome suggests that using a mobile-tracked device in an asymmetric VR learning environment can be an effective method for improving knowledge. The participant's ability to answer the knowledge questions correctly significantly increased after completing the learning tasks which indicates that the asymmetric learning approach using a tablet in VR is a promising tool for knowledge acquisition, specifically for topics that require collaboration. The study outcomes demonstrated that such an asymmetric VR multiplayer approach offers an effective way to overcome the issue that usually only one person is able to perform a VR learning environment reported by Pirker et al. [35]. The concept presented here could be an additional improvement for collaborative learning, strengthening teamwork, fostering critical thinking through knowledge asymmetry, and having a positive impact on the learning experience. This is in line with the asymmetric multiplayer approaches described by Karaosmanoglu et al. [22], Lee et al. [25], Smilovitch and Lachman [43]. It can be concluded that the participants enjoyed interacting with the learning content in a hands-on and interactive way. The knowledge questions show a significant improvement in the participant's knowledge about the topic.

Incorporating new forms of collaboration through mobile devices offers several opportunities to enhance the learning experience, such as increasing accessibility, flexibility, and convenience for learners. This setup enables new learning scenarios, new assignment design possibilities, and new forms of collaboration between the students. The use of mobile devices can provide immersive and interactive learning environments that engage learners in ways that traditional methods cannot equal. Furthermore, incorporating collaborative multiplayer elements in VR for mobile education can promote collaboration and critical thinking among learners. It is possible that individuals who rate their dominance as high on the SAM may also report higher levels of autonomy, as they might feel more in control of their actions and decisions within the virtual environment. Conversely, individuals who rate their dominance as low on the SAM may report lower levels of autonomy, as they may feel less in control of their actions and decisions.

7.1 Limitations

The study was designed as a first investigation into the level of dominance, social presence, and learning experience users felt. The main limitation of this study was the small number of participants. We recruited students, employees, and interns from a local education institution which results in a wide age range from 15 and 32. A smaller age range and participants with similar background knowledge would lead to more meaningful conclusions. All users were asked to rate both perspectives, which might influence their experience with the other, although they were instructed to respond only on the basis of the last version. Furthermore, the study did not include long-term effects. It would also be interesting to asses learning outcomes over a longer time period to obtain more detailed learning results.

8 CONCLUSION

In this paper, we present the design and implementation of an asymmetric multiplayer learning environment in VR. A color learning experiment was developed to investigate the dominance level, social presence as well as the learning experience and motivation of the users. In general, the participants were satisfied with the learning experience and were also able to improve their knowledge about the learning content. According to the evaluation results, participants in both perspectives rated in control similarly. Participants reported almost no negative feelings and felt empathy for the other user. Participants expressed their desire to use asymmetric multiplayer for learning purposes either with peers or domain experts. This indicates that educational applications involving multiple users are seen positively by most users. In addition, it suggests strong potential for collaboration within these types of learning systems which could be further explored in future research focusing on education and training applications within a collaborative virtual reality environment including handheld devices. In conclusion, the findings suggest that although many people prefer using a VR headset over tablets when entering immersive worlds, there is still interest in traditional forms such as handheld devices. Due to familiarity, users feel more comfortable interacting with tablets than with VR headsets. In the light of the potential benefits in terms of better knowledge acquisition and higher levels of engagement, integrating such asymmetric learning approaches into the classroom could be extremely beneficial. It provides teachers with an additional tool to adequately prepare students across a wide range of topics.

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Received January 2023; revised May 2023; accepted June 2023