Learning with immersive technologies : a VR task to study collaborative learning

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Learning with immersive technologies : a VR task to study collaborative learning Apprendre à l'aide des technologies immersives : une tâche en RV pour l'apprentissage collaboratif

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Immersive technologies hold significant promise in engaging students in educational activities. Theses technologies can foster interaction, immersion, and collaboration among students, benefits that are known to enhance various aspects of learning. However, collaboration in virtual reality (VR) can be challenging. Habits of collaboration developed in real life may not necessarily translate to such an environment. For instance, the lack of "social cues" in VR, such as facial expressions, may affect communication and problem solving, thus requiring us to adapt and reflect on how to apply this technology in educational settings. Nonetheless, VR also offers highly interesting new perspectives for education, enabling us to imagine new ways of working together. Therefore, it becomes imperative to closely explore the process of collaboration in VR, with a focus on learning, an area where VR is experiencing significant growth. In this regard, we take an existing educational task designed specifically for creative problem solving, and adapt it for VR. We build around this task a VR application that allows collaboration between two or more individuals engaging in problem solving. Our application provides a unique opportunity to study the collaborative processes involved in the specific context of learning, thereby opening new avenues to enhance educational experiences through VR.

Les technologies immersives sont prometteuses pour rendre attrayantes et motivantes les activités éducatives. Ces technologies peuvent favoriser l'interaction, l'immersion et la collaboration entre les étudiants, avantages connus pour améliorer divers aspects de l'apprentissage. Cependant, la collaboration dans un environnement de réalité virtuelle (RV) peut s'avérer difficile. En effet, les habitudes de collaboration développées dans la vie réelle ne s'appliquent pas nécessairement à cet environnement. Par exemple, l'absence d' "indices sociaux" dans la RV, tels que les expressions faciales, peut affecter la communication et la résolution de problèmes, cela nous demande de nous adapter et de réfléchir à la manière d'utiliser cette technologie dans des contextes éducatifs. Néanmoins, la RV offre également de nouvelles perspectives très intéressantes pour l'éducation, nous permettant d'imaginer de nouvelles façons de travailler ensemble. Il devient alors impératif d'étudier de près le processus de collaboration qui a lieu dans un environnement de RV, en mettant l'accent sur le domaine de l'éducation, dans lequel la RV connaît une croissance significative. Nous utilisons ici une tâche éducative existante, conçue spécifiquement pour la résolution créative de problèmes, et l'adaptons à la RV. Nous construisons autour de cette tâche une application de RV qui permet la collaboration entre deux ou plusieurs personnes impliquées dans la résolution d'un problème. Notre application offre ainsi une manière unique d'étudier les processus de collaboration dans le contexte spécifique de l'apprentissage, ouvrant de cette manière de nouvelles voies pour améliorer les expériences éducatives à l'aide de la RV.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; *Pointing*; Visualization techniques.

Additional Key Words and Phrases: VR, Collaboration, Learning, Education, Interaction, Immersion, IHM

Mots Clés et Phrases Supplémentaires: VR, Collaboration, Apprentissage, Education, Interaction, Immersion, IHM

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1 INTRODUCTION

Immersive technologies seem particularly promising for college education in order to engage students in educational activities. Various factors contribute to their effectiveness, including the potential for movement, motivational aspects [16], sustained interest, or even the "concrete" visualization of abstract concepts [5, 10]. Among these immersive technologies, virtual reality (VR) emerges as a particularly valuable tool in education [11], providing a dynamic platform for shared exploration and remote knowledge acquisition, fostering interaction and collaboration between students.

For instance, VR opens up new opportunities in terms of shared resources. When dealing with rare, expensive, or ethically sensitive materials in educational contexts, in VR students can gain practical experience in VR, bridging the gap between theoretical knowledge and hands-on manipulation. Moreover, individuals located in different cities can work together without the need for physical travel. This has become particularly relevant during the pandemic. The integration of these technologies into education is an ongoing trend, making it imperative to keep studying the educational mechanisms at play and develop valuable and high-quality educational experiences.

While collaborative learning is recognized for its positive impact on learning outcomes [9], there is a notable scarcity of studies investigating the specific mechanisms at play in collaborative VR learning environments. Despite the benefit of VR, it is crucial to acknowledge that it cannot precisely replicate real-life interactions, presenting challenges such as the absence of facial expressions and the concept of personal space [2], that can affect social interactions between students [19]. Consequently, there is a need for more research to comprehensively understand the dynamics of collaborative learning in VR and address its unique challenges. The study of VR in education also offers possibilities to develop new ways of collaborating, ways that would be unfeasible in the physical world. For instance, we could imagine sharing our field of view to others so that it becomes also their field of view when we want to show something to someone else.

Thus, in order to facilitate collaborative learning in optimal conditions, exploring VR techniques that enhance collaboration is deemed essential. Our long term objective is to design a range of techniques to improve collaboration within a VR environment, particularly in the field of education. We also aim to study how collaborative behavior may differ in VR compared to face-to-face and whether knowledge can be transferred between them. In order to do this, in this paper we start out by identifying a benchmark educational task that can then be used in comparative studies. We chose an existing task used to study creativity and computational thinking, and adapted it for VR. We report on a pilot study that suggests it is well suited for a VR experience and allows knowledge transfer between VR and the physical world.

2 MOTIVATION

Educational contexts are quite particular because they can encompass a wide range of audiences, determined by factors such as academic level (high school, higher education institutions, etc.) and the specific field of study.

In the field of education, the tasks chosen for studying immersive technologies and its link to education are usually situated learning tasks. This means that they are linked to a precise and given domain. For instance, the mathematical graph theory has been studied in VR [5] so has been the learning of hypsography in a collaborative immersive virtual environment [19]. This approach produces precise and relevant results for the specific area of application studied and is

Fig. 1. Physical cubes of the task Creacube

ecologically valid. However, we believe it is also important to adopt a complementary approach and study collaborative processes in more generic learning tasks.

These more generic tasks, do not require "expert knowledge", meaning a high level of expertise and specialized skills in a particular field, thus they allow for study findings that can be more generalized across disciplines. As a result, it could help reduce potential bias induced by the selection of participants in a specific field of study. For instance, socio-professional categories or gender variables may already be involved in the choice of studies [12, 17] and therefore have an influence of the results of the experiment. Or choosing a task that places a strong emphasis on written culture in an academic context may significantly favor certain segments of the population while disadvantaging others [15]. Thus we need benchmark tasks that do not concentrate on a specific educational discipline, but rather aim to identify a learning task that can be accomplished regardless of individuals' fields of study and previous knowledge.

Additionally, we are examining educational-oriented practical work, which refers to pedagogical formats widely used, particularly in the teaching of disciplines that require combining collective thinking and actions [6]. Practical work highlights students' interaction with their environment, while being usually conducted in small groups, often in pairs or trios, encouraging interactions among students, with collaboration being of major importance [1] [18]. This format, intended to foster students' interaction with educational materials and their autonomy in action, seems particularly well-suited to virtual reality with an HMD (head-mounted display). We thus looked for a task that emphasizes manipulation rather than being a purely visual task.

Considering the potential discomfort associated with prolonged use of a virtual reality headset [8], we took into account the activity's duration, ensuring that it is not too long. Additionally, we aimed for a task conducive to collaboration involving multiple participants.

Our choice thus fell upon a learning task already employed in the academic field, known as "Creacube" and introduced by Romero *et al.* [13], discussed next.

3 TASK AND VR PROTOTYPE

In order to study various techniques promoting awareness and their impact on collaboration between two individuals in an educational/learning context, we developed a prototype of a VR application designed for two people.

3.1 Physical Educative Task

This prototype is based on a learning task called "Creacube", introduced by Romero *et al.*. This is a creative problem-solving task engaging learners in computational thinking. This means that it initiates learners to several principles of computational thinking (CT), such as the decomposition of a problem, the application of knowledge gained during the resolution of previous problems, and the identification of a solution to the problem after all sub-problems have been addressed. This principle of computational thinking develops critical and analytical thinking among students, and supports STEAM (Science, Technology, Engineering, Art and Mathematics) education [14]. The task has been used in collaborative contexts, to explore conversation and social group process and their impact on problem solving capabilities of a group [4].

The task is made up of 4 cubes from the modular robotics material Cubelets[1] as shown in Figure 1 and involves manipulating and assembling these cubes in order to build a vehicle that moves autonomously from an initial point to an end point. Each cube has its own function : sensor, actuator, inverter or power on/off [13], that are not explained and need to be determined by participants. Different cube configurations will lead to different behaviour. For instance, in order to function, the inverter cube must be located between the sensor cube and the actuator cube (which has wheels), otherwise the assembly of cubes will not move.

In addition, as Romero *et al.* explained: *"This task may seem simple at first, involving the assembly of 4 cubes. However, there are a limited number of ways to assemble the pieces in a balanced structure. For example, it's possible to assemble the parts horizontally, or to place the cubes on two full or partial cube levels. But if the assembly is vertical, in a column, the structure does not maintain stability during displacement."* For instance, we can see the vertical assembly falling in Figure 2-c.

3.2 Transition to VR

We developed a prototype that allows performing the "Creacube" task in pairs within a virtual reality environment.

To develop this prototype, we sought to stay as close as possible to the physical CreaCube task while making the necessary adaptations to ensure it works in virtual reality. Indeed, it is important to make sure that the cubes' behaviors are similar, so that they can be reproduced in the physical world to allow for knowledge to be transferred between the two.

The cubes, as in the physical world, exhibit affordances—features that suggest their mode of use or utility to the user (see Figure 2-a). The main affordances here are the wheels and the button. Furthermore, if the cubes are connected to the battery and the battery is turned on, the cubes will be "illuminated", meaning they will take on a brighter color than their base color as in Figure 2-b. We choose to enhance this illumination to make sure people see the change as in the physical task it only lights up a small LED on each cube.

We have also chosen to replicate real-world behaviors by ensuring that in a collaborative setting, it is possible to take an object from someone else's hands. In other words, the ownership associated with the objects is determined by the last person who grabbed the object. Moreover, to make these behaviors possible, we created avatars with two hands and a head for each participant [7]. Through this embodiment, we wish to make actions easiest to carry out (for instance grab an object as we can see in Figure 2-a) as well as to create a greater social presence, that is to say the sense of "being there with someone else" [3].

[1]https://modrobotics.com/

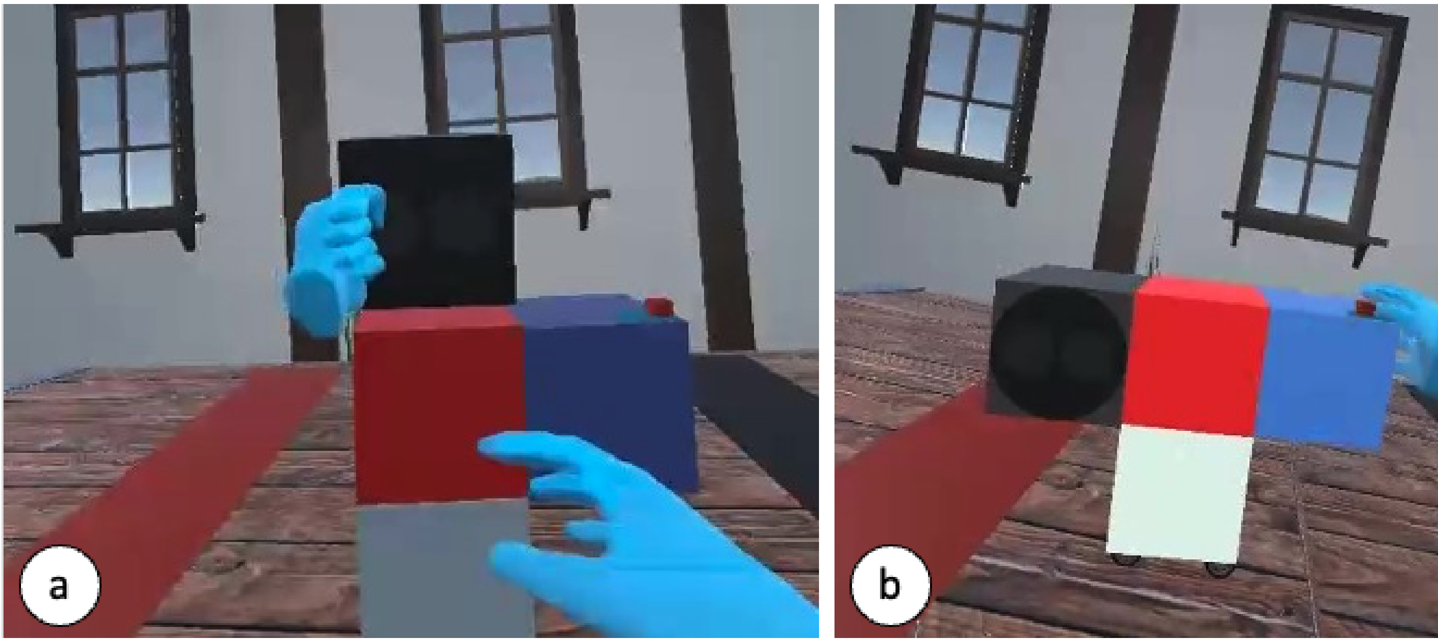

Fig. 2. VR prototype of the CreaCube task. (a) Assembly of cubes being built; (b) Assembly of cubes rolling from the red band to the black one; (c) Assembly of cubes falling due to gravity

To simplify interaction with the virtual environment, we chose to minimize the use of control buttons, which are only used for grabbing a cube or for displacement. We incorporated haptic feedback and associated sounds with various interactions in the environment to enhance the presence and immersion of the user.

While it is beyond the purposes of this article, we note that we have created an internal representation of cube configurations and associated behaviors (in the form of a connectivity graph) that is very easy to extend to new cubes and behaviors.

To validate our choice of this task, we carried out pilot tests to ensure that the task was (i) functional in virtual reality, and (ii) knowledge acquired in virtual reality could be transferred to the physical world.

4 PILOT STUDY

We tested our task and environment within a pilot study to determine if it is achievable in VR. And to investigate if it is a task where the acquired knowledge in VR might be transferable to the physical environment.

This pilot study is designed for a solo user. The decision to conduct this experiment in solo mode rather than collaboratively is based on several considerations. We opted for a pilot study in solo mode to initially assess if interactions with the cubes proceed smoothly. There is indeed a possibility that the task may not work as intended if participants struggle to use the controls associated with Virtual Reality. Subsequently, we aim to investigate whether the exploration of cubes unfolds seamlessly and if participants successfully identify functional assembly solutions that can be transferred to the physical world. This approach allows us to refine the prototype, addressing both its usability and the understanding of the virtual task. Insights gained from this solo study will contribute to potential enhancements, ensuring a more user-friendly experience and a deeper comprehension of the virtual task itself.

The 7 participants in this study are aged from 22 to 26 years old. They have previously used virtual reality headsets with varying levels of expertise, ranging from VR programming (1 person) to simply watching a video with a VR headset.

4.1 Materials and Technology

The development environment for this project utilizes Unity version 2021.3.22f1. The virtual reality experience is designed for the Oculus Quest 2 headset. The project runs on a high-performance PC featuring a 12th Gen Intel(R) Core(TM) i9-12900H processor with a base frequency of 2.50 GHz. The system operates on a 64-bit operating system, x64 processor architecture, and is equipped with 16 GB of RAM. Graphics rendering is handled by the NVIDIA RTX A2000 8GB.

4.2 Procedure

The following experimental approach is designed to assess the feasibility of the virtualized CreaCube task: the experience is divided into several distinct phases, unfolding in the following order: general explanation, tutorial, virtual reality experience, physical world experience, questionnaire.

Firstly, a detailed explanation of the virtual reality controllers' functionalities is presented to the participants. This includes a description of the different buttons and their specific actions. The tutorial phase takes place in a dedicated virtual room, providing participants with the opportunity to ask additional questions about the controllers. These questions are encouraged and taken into account to ensure a thorough understanding before the virtual reality experience phase. In this environment, participants are invited to move around and grab cubes. The virtual experience room constitutes the third phase. Participants receive the following instructions : "You must build a vehicle consisting of 4 pieces that moves by itself from the red zone to the black zone. I can give you the instructions again at any time if needed." After the VR experience, participants were asked to explain their understanding of what role each of the cubes played in the context of the task. Next, participants perform the same task in the physical world, using 4 cubes that were hidden from them until that point. The instructions are the same, with the exception that they cannot reproduce the same configuration of assembled cubes they used in the virtual environment to complete the task. In other words, they had to find a different cube configuration that worked. If they had understood the roles of the cubes in VR this would directly benefit this task. This time, the same question about the role of each cube is posed to participants to see if they have changed their minds or not. This is followed by a series of 8 questions aimed at qualitatively understanding how the transition between VR and the physical world occurred for users and identifying points that can be improved in the virtual application (e.g., in terms of interaction ergonomics, understanding affordances, etc.).

4.3 Observations

Usability. The interaction in this context sometimes proves challenging, especially when people are unfamiliar with VR, it is thus marked by highly varied behaviors from one person to another. For instance, some individuals successfully complete the virtual task in less than a minute, while others take closer to 10 minutes (See Figure 3). Despite these disparities, a consistent pattern emerges: everyone has managed to perform both tasks, physical and virtual. This success the task is indeed feasible in VR.

A participant suggested adding sounds to the VR experience, such as "clicks" when cubes attach. This could assist users in realizing whether their actions have consequences in the virtual environment more reliably than with only visual cues (for example, when a button moves as a user interacts with it). Some participants also found that the two

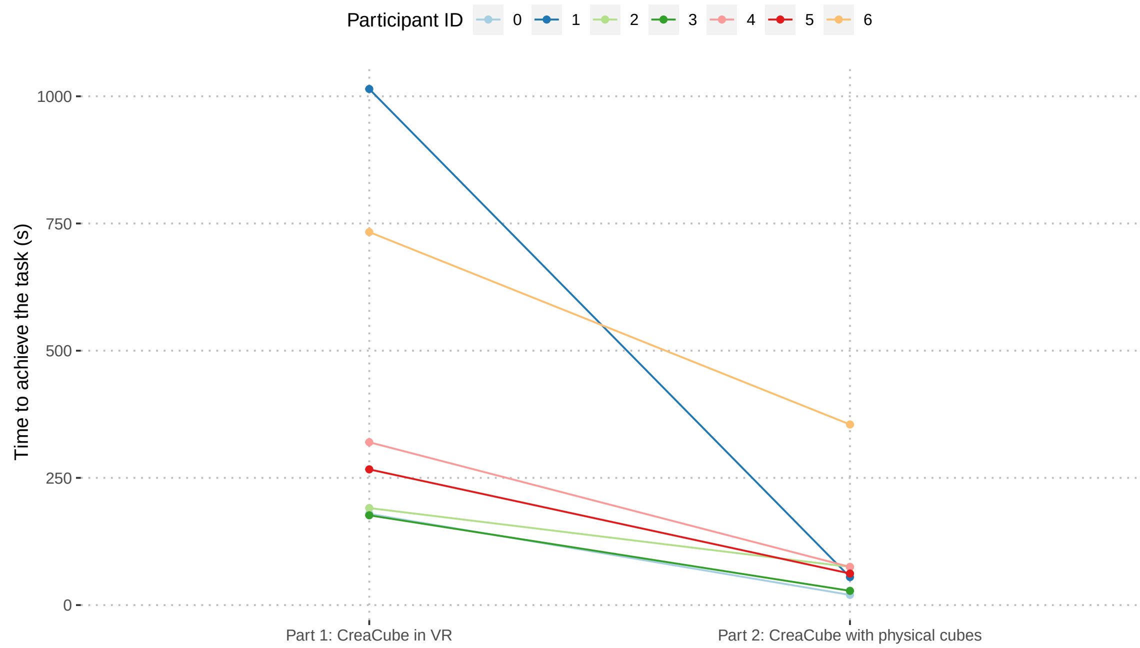

Fig. 3. Time to finish the task for each part of the study for each participant.

circles on the sensor cube looked quite different in VR compared to the physical version, describing them as "resembling magnets in VR" or even as "buttons, whereas in the physical environment, they look like eyes." Accordingly, we changed the visuals circles of the sensor cubes to make them more similar to the physical version and we added sounds for moments when cubes attached, when the power is turned on or off, and when the wheels are in motion.

Our observations also suggest that all participants understood the functionality of the wheel-equipped cube and the cube with an activation button in the VR experience. The inverse cube and the sensor cube proved more challenging for participants to comprehend. No one could determine the purpose of the inverter cube, while several mentioned "eyes" or "headlights" for the sensor cube during the VR task (a similarity noted in the physical task in the past [**?**]). Only one person immediately grasped the functionality of the sensor cube by physically handling it in part 2, recognizing the transparent reflection of the two circles on the sensor, and leveraging their prior knowledge of proximity sensors.

Transfer. Moreover, 5 out of 7 individuals did not change their perceptions of the cube functions after handling their physical counterparts, thus indicating that they did not discover any new functionalities in part 2. When looking at the time participants took to finish the task in both parts of the study in Figure 3, we can see that all participants took less time to assemble the vehicles in part 2 with the physical cubes than in part 1 in VR. This suggests that they were able to transfer the knowledge they acquired in the VR prototype. To confirm that this difference is not only due to the difference of environment (VR vs. physical), we also looked at the number of configurations[2] tried in each part, in Figure 4. This clearly showed that participants tried fewer configurations in part 2, suggesting that they had already

[2]A configuration is defined here as an assembly of 2 or more cubes.

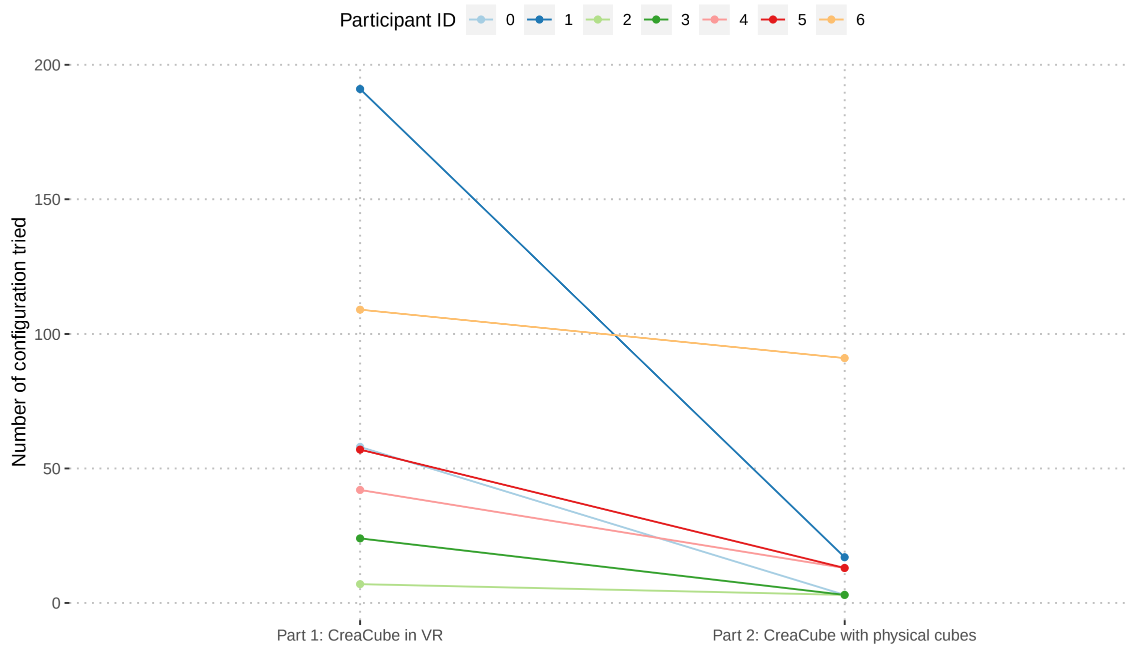

Fig. 4. Number of configurations tried for each part of the study for each participant.

understood, using the VR prototype, the functionality of the cubes. Thus, they were overall able to transfer a large part of their knowledge from VR into the physical world, making fewer errors while trying different configurations.

5 CONCLUSION AND PERSPECTIVES

Studying education in collaborative VR environments requires choosing appropriate learning tasks. In this article, we introduced a VR version of an open learning task that can be done collaboratively (in pairs). The choice of this task was notably motivated by the fact that there is no prerequisite expert knowledge needed, the task does not have an excessively long duration, and it appears interesting from an educational standpoint. This task indeed highlights the skills used in problem-solving, the creative aspect developed by individuals in understanding a task, and computational thinking. We tested the usability of this task, meaning to study first if the task is functional in VR and also if the participants understand the educational task, succeed in finding a solution, and re-use the knowledge they acquire in the VR task in the physical world. Next, we are going to test the usability of this task in a collaborative setting with dyads in order to validate this collaborative task. More precisely, if the participants are satisfied with their communication with the other person, if the interactions are fluid enough and if they can correctly complete the task.

Our final objective is to explore various techniques aimed at enhancing collaboration in the context of education within a virtual environment. We seek to investigate whether the incorporation of techniques designed to improve mutual awareness can foster collaboration in VR, particularly in the educational domain. And whether the knowledge gained in VR is more generally transferable to physical tasks. Additionally, we aim to determine if there are significant differences in the learning experience depending on the available awareness techniques such as the presence of an avatar or the provision of visual feedback on the other person's actions. Concurrently, we will study the impact of adding awareness/collaboration techniques on students' behavior, including aspects like the proportion of talking, to gain a better understanding of communication dynamics in this virtual environment.

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REFERENCES

[1] Nicolas Balacheff, Sten Ludvigsen, Ton Jong, Ard Lazonder, and Sally Barnes. 2009. *Technology-Enhanced Learning. Principles and products.* https://doi.org/10.1007/978-1-4020-9827-7

[2] Mark Billinghurs. [n.d.].

[3] Frank Biocca, Chad Harms, and Judee Burgoon. 2003. Towards A More Robust Theory and Measure of Social Presence: Review and Suggested Criteria. *Presence* 12 (10 2003), 456–480. https://doi.org/10.1162/105474603322761270

[4] Laura Cassone, Margarida Romero, and Shirin Basiri Esfahani. 2021. Group processes and creative components in a problem-solving task with modular robotics. *Journal of Computers in Education* 8, 1 (2021), 87–107.

[5] Julia Chatain, Rudolf Varga, Violaine Fayolle, Manu Kapur, and Robert W. Sumner. 2023. Grounding Graph Theory in Embodied Concreteness with Virtual Reality. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (Warsaw, Poland) *(TEI '23)*. Association for Computing Machinery, New York, NY, USA, Article 2, 13 pages. https://doi.org/10.1145/3569009.3572733

[6] Jérôme Guérin. 2013. Configurations d'activité collective et processus d'apprentissage lors de travaux pratiques. *Carrefours de l'éducation* 35, 1 (2013), 179–195. https://doi.org/10.3917/cdle.035.0179 Place: Paris Publisher: Armand Colin.

[7] Fernanda Herrera, Soo Youn Oh, and Jeremy N. Bailenson. 2018. Effect of Behavioral Realism on Social Interactions Inside Collaborative Virtual Environments. *Presence: Teleoperators and Virtual Environments* 27, 2 (02 2018), 163–182. https://doi.org/10.1162/pres_a_00324 arXiv:https://direct.mit.edu/pvar/article-pdf/27/2/163/2003610/pres_a_00324.pdf

[8] Eunjee Kim and Gwanseob Shin. 2020. User discomfort while using a virtual reality headset as a personal viewing system for text-intensive office tasks. *Ergonomics* 64 (12 2020), 1–23. https://doi.org/10.1080/00140139.2020.1869320

[9] Marjan Laal and Seyed Mohammad Ghodsi. 2012. Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences* 31 (2012), 486–490. https://doi.org/10.1016/j.sbspro.2011.12.091 World Conference on Learning, Teaching Administration - 2011.

[10] Guido Makransky and Gustav B. Petersen. 2021. The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review* 33, 3 (Sept. 2021), 937–958. https://doi.org/10.1007/s10648-020-09586-2

[11] Tassos A. Mikropoulos and Antonis Natsis. 2011. Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers Education* 56, 3 (2011), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020

[12] María del Carmen Olmos-Gómez, Mónica Luque-Suárez, Diego Becerril-Ruiz, and Jesús Manuel Cuevas-Rincón. 2021. Gender and Socioeconomic Status as Factors of Individual Differences in Pre-University Students' Decision-Making for Careers, with a Focus on Family Influence and Psychosocial Factors. *International Journal of Environmental Research and Public Health* 18, 3 (2021). https://doi.org/10.3390/ijerph18031344

[13] Margarida Romero, Dayle David, and Benjamin Lille. 2018. CreaCube, a Playful Activity with Modular Robotics. In *International Conference Games and Learning Alliance*. https://api.semanticscholar.org/CorpusID:59524240

[14] Noor Desiro Saidin, Fariza Khalid, Rohanilah Martin, Yogeswary Kuppusamy, and Nalini Munusamy. 2021. Benefits and Challenges of Applying Computational Thinking in Education. *International Journal of Information and Education Technology* 11 (01 2021), 248–254. https://doi.org/10.18178/ijiet.2021.11.5.1519

[15] Nic Spaull and John Comings. 2019. *Improving Early Literacy Outcomes: Curriculum, Teaching, and Assessment.* BRILL. Google-Books-ID: gTGbDwAAQBAJ.

[16] Ekaterina Sviridova, Elena Yastrebova, Gulmira Bakirova, and Fayruza Rebrina. 2023. Immersive technologies as an innovative tool to increase academic success and motivation in higher education. *Frontiers in Education* 8 (2023). https://www.frontiersin.org/articles/10.3389/feduc.2023.1192760

[17] Jerry Trusty, Chester Robinson, Maximino Plata, and Kok-Mun Ng. 2000. Effects of Gender, Socioeconomic Status, and Early Academic Performance on Postsecondary Educational Choice. *Journal of Counseling Development* 78 (10 2000). https://doi.org/10.1002/j.1556-6676.2000.tb01930.x

[18] Judith D. Wilson, Nathan Hoskin, and John T. Nosek. 1993. The Benefits of Collaboration for Student Programmers. In *Proceedings of the Twenty-Fourth SIGCSE Technical Symposium on Computer Science Education* (Indianapolis, Indiana, USA) *(SIGCSE '93)*. Association for Computing Machinery, New York, NY, USA, 160–164. https://doi.org/10.1145/169070.169383

[19] Čeněk Šašinka, Zdeněk Stachoň, Michal Sedlák, Jiří Chmelík, Lukáš Herman, Petr Kubíček, Alžběta Šašinková, Milan Doležal, Hynek Tejkl, Tomáš Urbánek, Hana Svatoňová, Pavel Ugwitz, and Vojtěch Juřík. 2019. Collaborative Immersive Virtual Environments for Education in Geography. *ISPRS International Journal of Geo-Information* 8, 1 (2019). https://doi.org/10.3390/ijgi8010003