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iHABS: Collaborative Learning in a Networked, Immersive Simulation Environment

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Abstract. Three-dimensional Virtual Learning Environments (VLEs), with their unique features of immersion, presence, and direct engagement, offer considerable promise for the design of effective constructivist learning environments. Collaboration within a VLE should facilitate active and engaged forms of learning, thereby enriching and enhancing the learning process. However, research performed to date has not unequivocally and consistently demonstrated positive and sustainable learning effects. In this paper, we report our study on *iHABs*, a networked, immersive hot air ballooning simulation program. *iHABS* allows students to learn underlying physics principles related to buoyancy in a fun, engaging, and collaborative manner. The key goals of our research were to evaluate the effectiveness of collaborative learning in a VLE and to assess the impact of presence in such a learning setting. In addition, we studied how factors such as individual characteristics, relationship between the participants, differences in level of understanding, and task structure affect collaboration within the VLE. An empirical evaluation was conducted, and the research findings are presented in this paper.

1. Introduction

Virtual Reality (VR) incorporates various unique features such as immersion, presence, and direct engagement. These unique features provide students with certain learning affordances that are not otherwise available. Some of these unique capabilities include allowing students to directly manipulate and scale objects in virtual environments, visualize abstract concepts using virtual metaphors, and interact with events that are usually precluded for reasons of distance, time, or safety.

Collaborative learning contexts, compared to individual and competitive learning situations, can help students attain to a higher level of achievement, raise their problem solving abilities, and offer cognitive advantages to learners [12]. Coupled with the unique features of VR, collaboration within Virtual Learning Environments (VLEs) should facilitate the articulation of ideas and co-construction of new concepts, thereby aiding the process of conceptual change and enhancing the learning experience.

In our research project, we developed a networked, immersive hot air balloon simulation (iHABS) based on educational theories of cognitive and social constructivism. Haugland [7] stated that various topics of physics could be taught through the domain of hot air ballooning, specifically Buoyant Force, properties of air, heat expansion, speed and density. Among these topics, Buoyant Force, is the most common concept that is misunderstood by students. Use of item 12D of the Force Concept Inventory [9] showed that Buoyant force was hardly recognized by students at any level. Interviews with 16 graduate students revealed that only two of them really understood the concept of Buoyant Force. Thus, it is appropriate to use iHABS to investigate the capability of immersive VLEs to correct the misconception on the concept of Buoyant Force among students.

iHABS is designed to address some of the unresolved issues of VLEs. It makes good use of the specific features of VR and seeks to rely on cognitive benefits of collaboration to effect the conceptual change in students. Specifically, the goals of our research are threefold. First, we wish to demonstrate that iHABS, with its unique VR features, can effect conceptual change in students. Second, we aim to investigate the process and implications of applying collaboration in VLEs to aid conceptual change. Third, we wish to examine how factors such as individual characteristics, relationship between participants, differences in level of understanding, and task structure affect the collaboration process within VLE.

2. Background

Although VR in education is a relatively young field, it is growing rapidly. In Youngblut's [15] comprehensive review on educational uses of virtual reality, she identified approximately 25 immersive VLEs. Various studies have conclusively demonstrated the ability of VR to teach content under certain prescribed conditions [1, 2, 6]. However, there is little research connected with conceptual learning.

With increasing hardware performance and advances in network technology, researchers have started to investigate the potential and implications of incorporating collaboration within VLEs. Collaborative learning enables students to learn in relatively realistic, cognitively motivating, and socially enriched learning contexts. Collaboration experience can also facilitate the development of planning and problem solving skills. Crook [5] noted that collaborative learning has three cognitive benefits; articulation, conflict, and co-construction.

At this point in time, research in collaborative VLEs is still in its infancy. Limited empirical evaluations have been performed to date. Only three well-known and established collaborative, immersive VLE projects have been reported on so far. They are the NICE (Narrative Immersive Constuctionist/Collaborative Environments) project [2], the Round Earth Project [11], and GCW (Global World Change) [10].

The collaborative learning process in NICE is unstructured and undirected. The study conducted by the researchers concluded that collaboration proved to be a double-edged sword. The presence of avatars representing remote users was a strong spur to social interaction, but this arose at the expense of the intended science learning. The Round Earth Project, successor to the NICE project, has remedied the deficiencies in NICE to support conceptual learning. Findings from the pilot studies of this project showed few instances of complete, fundamental change in conceptual models among students. Many students still held on tightly to their initial notion that the Earth is flat. The failure was attributed to the bridging procedure that introduced too many intermediate representations. In addition the cognitive demands were too great for the students to handle.

The GCW study demonstrated successful conceptual change in many students. The researchers observed students dealing with intellectual conflicts, articulating beliefs, and co-constructing theories while interacting in the VLE. They expressed the belief that conceptual change *can* occur as a result of these meaningful interactions within the VLE. However, there was no direct evidence that collaboration within the immersive VLE itself aided the process of conceptual change.

Overall, research on collaboration in VLEs is scattered, and there is insufficient robust evidence of the educational effectiveness of applying collaboration within VLEs. Factors present in collaborative VLEs and their influence on conceptual learning have not been studied to a great extent. It should be evident, therefore, that the field of collaborative VLEs remains open, and it requires further focused and systematic research.

3. Pedagogy Support

Good pedagogy demands identifying the best fit between tools/techniques and learning objectives. The design of iHABS is based on the educational theories of cognitive and social constructivism. VLEs designed using the constructivist approach offer great potential for providing powerful learning experiences. Through student interaction within a constructivist VLE, cognitive dissonance can be triggered and a process of conceptual change scaffolded.

Cognitive constructivism emphasizes that learning is an active process, and direct experience, making errors, and looking for solutions are vital for the assimilation and accommodation of new information. According to Youngblut [15], all educational VR applications that explicitly embody some form of pedagogy support constructivist learning, either using an *experiential learning* or a *guided-inquiry* approach. In iHABS, both of these approaches have been integrated. We believe that this integration helps to provide a more effective and engaging learning experience.

iHABS enables students to enjoy first-person knowledge about piloting a hot air balloon, something accessible to them in real life only as a third person experience. Students are required to land on a suitable and safe landing spot. If they fail to do so, they will crash the hot air balloon. This active, *experiential* approach is believed to help motivate students to engage in the learning process. To enhance the effectiveness of learning, iHABS also relies on the *guided-inquiry* approach. This approach is implemented in several ways. First, with the use of virtual metaphors, iHABS allows students to virtually experience and be aware of the changes in weather conditions as the balloon rises to a higher altitude. Second, students are allowed to change various parameters such as the balloon size, balloon load, ground temperature, and sea-level pressure. They can then observe how these actions affect the maximum altitude and ascending rate of the balloon. In addition, various charts are provided to help them visualize the changes of atmospheric temperature, pressure and wind speed that arise with the change in altitude.

The learning approach based on Vygotsky's [13] *social constructivism* views learning and human development as a social, collaborative activity. Interaction among peers that revolves around appropriate collaborative tasks in a given learning environment can help students to master critical concepts. In iHABS, students can communicate with each other using an audio chat facility that allows them to communicate using their normal voice. Use of this facility can improve communication, facilitate collaboration and enhance the feeling of co-presence [10]. Students are given collaborative tasks that facilitate their collaboratively constructing knowledge related to hot air ballooning physics concepts. To complete these tasks, students are required to verbalize their ideas and make their thinking public and explicit. By “self-explaining,” students become aware of gaps and possible inconsistencies in their understanding, and this provides a trigger for them to revise their conceptual model [4]. In addition, they can also become aware of gaps and inconsistencies in the reasoning of their peer’s. While carrying out the collaborative tasks, students can also compare and discuss their simulation results and co-construct their knowledge relating to the physics of hot air ballooning by building upon one another’s ideas. This form of learning promotes peer-to-peer collaboration and supports mutual sense-making.

4. iHABS Learning Environment

iHABS is an active experiential and exploratory learning environment for secondary through university level students. The design framework and network architecture of iHABS is based on the C–VISions (Collaborative, Virtual, Interactive Simulations) system [3]. In iHABS, users see the virtual world through the HMD that presents a stereoscopic view of the island. They interact with the virtual world using a data glove. Interaction techniques are designed based on the criteria of naturalness, sense of presence, accuracy, ease of learning, and ease of use. For *navigation* around the virtual world, a hybrid navigation method was implemented in iHABS. The *natural walking method* was used for short distance movement, and the *gaze-directed steering method* was used for remote distance navigation. In addition, to allow more flexible navigation, the *target-based method* was also implemented to allow users to survey other parts of the virtual world easily before taking off in a hot air balloon. For selection of virtual objects and virtual menus, the *ray-casting method* was implemented.

The *first-person view* was implemented in iHABS. Thus, users do not see themselves except for the virtual hand that is used for interaction. All other users in the virtual world are represented as avatars. The use of avatars promotes user interaction because it allows users to establish their sense of presence in the virtual world by creating the sense of "being there" [8]. Users can communicate and collaborate with each other verbally using an audio chat system. A snapshot of two avatars at the iHABS take-off site is shown in Figure 1.

In order to pilot a hot air balloon, students can access a *control panel* inside the hot air balloon. The control panel is illustrated in Figure 2. The basic components of the control panel consist of the temperature control slider, the altimeter, the variometer, the timer, and the fuel indicator. Among these components, only the temperature control slider is operable by users. Using the data glove, users can select the slider. On selection, the *virtual keypad*, as illustrated in Figure 3, appears, and it allows users to set the temperature of the hot air balloon. Several additional components that are simulated dynamically in real-time, such as atmospheric variables and balloon variables indicators, are embedded in the control panel to guide users in constructing knowledge on the pertinent physics principles.

iHABS also contains a *virtual toolkit* that allows users to change various simulation parameters, namely the sea-level pressure, ground temperature, balloon size, and balloon load. In addition, users can access a *virtual menu* that allows them to activate certain system commands. More details on the interaction techniques and system description of iHABS can be found in Wong, and Chee [14].

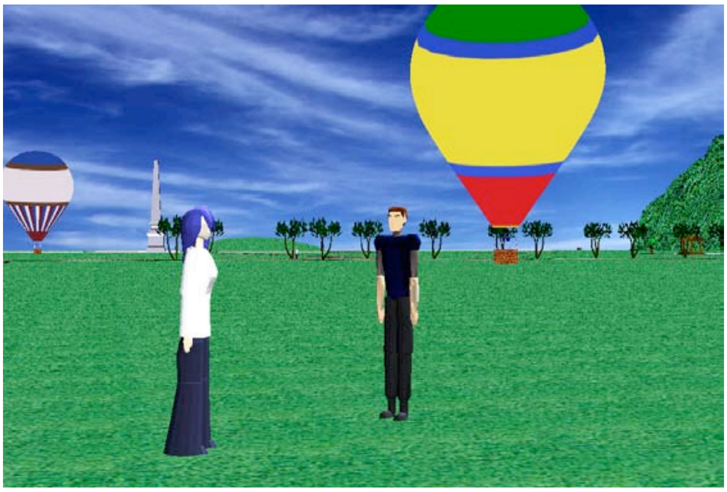

Figure 1: Two avatars at iHABS take-off site

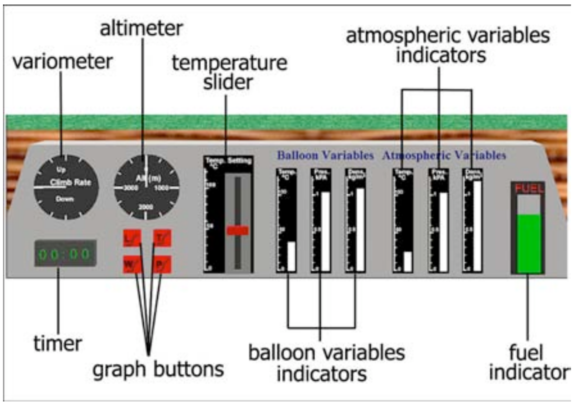

Figure 2: The control panel of a hot air balloon

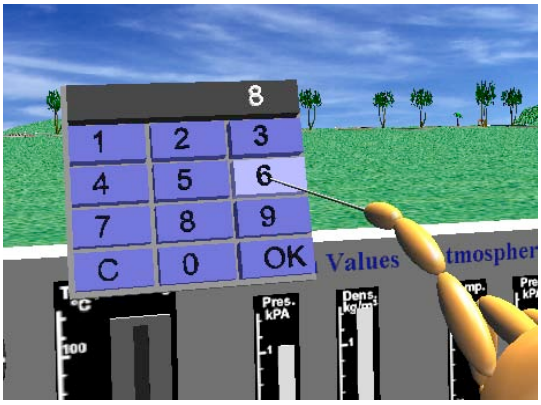

Figure 3: Keying value using the virtual keypad.

5. Design of Study

In our study, the subject pool was a group of university students comprising ten males and two females. Of these students, eight were graduate students and four were undergraduate students. In terms of faculty distribution, eight were computer science students, three were science students, and one was an arts student. They were divided into six teams of two students each. For the purpose of studying how various factors affect collaborative learning in VLEs, the composition of the teams reflected differences in terms of relationship between the partners, level of understanding, and maturity level. The composition of the student teams is shown in Table 1.

Table 1: Composition of students for the study

Pairs	First student	Second student	Knew each other prior to user study
Pair 1	Male Undergraduate Science	Male Undergraduate Science	No
Pair 2	Male Graduate Comp. Science	Male Undergraduate Science	No
Pair 3	Male Graduate Comp. Science	Female Undergraduate Arts	No
Pair 4	Male Graduate Comp. Science	Female Graduate Comp. Science	Yes
Pair 5	Male Graduate Comp. Science	Male Graduate Comp. Science	Yes
Pair 6	Male Graduate Comp. Science	Male Graduate Comp. Science	Yes

The keys to effective collaborative learning require application of effective *collaborative strategies* and *structuring tasks* to support collaboration . In this study, the collaborative strategy used was dividing the students into teams of two, assigning them the basic task of piloting hot air balloons, and asking them to complete two learning-related collaborative tasks. The two students of each pair were assigned to fly separate balloons of different size. During the balloon flight, they were requested to work collaboratively to find out why a hot air balloon rises and how balloon sizes and temperature affect the ascent rate and maximum altitude.

Figure 4: A pair of students collaborating in the iHABS.

The activities in each session of the iHABS study took approximately one and a half hours to complete. This period of time included that allocated for pre-test, training, collaborative activity, post-test, and completing a questionnaire. The study session commenced with the pre-test. The questions in the pre-test attempted to identify students' existing knowledge on the physics of hot air ballooning. Next, students went through a training session on how to use the VR devices and the iHABS user interface. This training helped to reduce the potential of unfamiliar user-system interactions interfering with the learning experience of the students. After the training, students started the collaborative activity in iHABS. Figure 4 illustrates two students collaborating in the iHABS VLE. In the iHABS VLE, they learned how to pilot and fly the balloon. Throughout the activity, they could collaborate with each other to complete the assigned tasks. They were given approximately 20 minutes for this activity. Upon emerging from the VR experience, the students were asked to complete a questionnaire and a post-test. The result of the post-test was compared with the pre-test results to establish the students' learning outcome.

6. Observation and Findings

The data from our empirical study were collected using the methods of observation, pre-test and post-test, questionnaire, and informal interview. The findings below are based on the five pairs of students who completed the collaboration activity. Of these five pairs of students, two pairs of students knew each other prior to the user study; the other three pairs were strangers to each other.

6.1 Factors affecting collaboration

Based on observation, only four pairs of students actively collaborated with each other to discuss the physics related to hot air ballooning. Two of these pairs, Pair 1 and Pair 4, took a similar, but safe approach. They focused on the easier task of trying to understand how balloon size and temperature affect balloon ascent rate and maximum altitude. Throughout the collaborative session, they were observed actively comparing only their ascent rate and height.

The students comprising Pairs 2 and 3 exhibited a more meaningful and higher level of collaborative activity. These pairs of students were seen actively engaged in articulating their ideas, resolving conflicts between themselves, and co-constructing knowledge on the underlying physics of hot air ballooning. Pair 2, comprising two males, a computer science graduate and a science undergraduate, adopted an interesting and creative approach. They set the same burner temperature, took off together, and observed the different ascent rate of both balloons. They then set the common objective of flying at the same height. They planned to achieve this goal by having the slower balloon increase its temperature so that it would climb faster. However, their mission to fly at the same height was not successful. From the interview with this pair of students, they indicated that the available travel time of the hot air balloon was too short to allow them to focus on multiple goals. Pair 3 consisted of a male computer science graduate student and a female arts undergraduate. They tried to focus on both the learning-related tasks. Throughout their VR experience, they actively discussed various aspects of physics. Both of these pairs of students expressed a high level of enjoyment.

Interestingly, the students who comprised Pairs 2 and 3 and who exhibited a higher degree of collaboration were strangers to each other prior to this user study. This finding contradicts an earlier study on collaborative learning indicating that students collaborate better with people whom they know beforehand and are comfortable with. It clearly demonstrates the potential of VR to facilitate and promote collaboration within VLEs. When the students were fully immersed in multi-participant VLEs, they lost their sense of individualness and shyness. They become more open and felt free to express their ideas and opinions. The virtual interface succeeded in removing the psychological barrier that is often an obstacle to effective communication between strangers in normal face to face communication.

In addition, the students in Pairs 2 and 3 were from different faculties and consisted of a graduate and an undergraduate. Thus, they possessed different levels of physics understanding and possibly were different in their level of maturity. Given these differences, we might have expected the graduate to exhibit dominant behavior over the undergraduate. However, such dominance was not exhibited. Both pairs of students communicated effectively. Individuals in the pairs were observed verbalizing their ideas and opinions alternately. Contrary to expectation, the differences in their level of understanding made them more open to each other’s perspective. They did not stubbornly hold on to their own ideas and opinions.

Students in Pair 5 who did not collaborate well were acquainted with each other beforehand. Their failure to collaborate actively was due mainly to the arrogant and “don’t care” attitude of one of the students. This student thought that he knew everything about hot air ballooning and was not motivated to collaborate to perform the tasks presented. He was more interested in experiencing what immersive VR feels like. However, a point to be noted is that this student did show improvement in his post-test score.

Overall, the above findings indicate that collaborative VLEs can reduce the negative impact of individual differences between students to some extent. However, over-strong individual characteristics may continue to limit the overall effectiveness of collaboration within VLEs.

6.2 Learning Outcome

The pre-test results revealed that most of the students held certain misconceptions on various principles related to the physics of hot air ballooning. 80% of the students were ignorant of the fact that a hot air balloon flies according to the direction of the wind. During their VR experience in iHABS, they tried to look for ways to steer the hot air balloon in a specific direction. 40% of the students mistakenly thought that a smaller hot air balloon can attain a higher maximum altitude compared to a larger hot air balloon. This misconception arose because students thought that a bigger hot air balloon is heavier, causing it to be less buoyant than the smaller hot air balloon. 50% of the students held the wrong concept that a hot air balloon stays afloat better when the surrounding air is hotter. In addition, 60% of the students also mistakenly thought that the surrounding air generates a net downward force instead of an upward force on a volume of air.

Comparison between the pre-test and post-test results provides evidence that learning in iHABS produced a positive learning outcome. Table 2 shows the comparison between pre-test and post-test scores on the questions related to concepts that students commonly misunderstood.

Table 2: Comparison between pre-test and post-test results

Questions related to the following concepts		**% Correct**	
		Pre Test	**Post Test**
1	A pilot cannot control the direction of a hot air balloon.	20%	100%
2	Hot air balloon stays afloat better when air surrounding it is cooler.	50%	100%
3	A bigger hot air balloon can reach a higher altitude compared to a smaller hot air balloon.	60%	100%
4	The greater the volume of an object, the greater the buoyant force.	70%	100%
5	Forces acting on a volume of air are gravity and a net upward force generated by the surrounding air.	40%	40%

From the results of questions 1 to 4 in the post-test, we observed that all students gained correct understanding on four physics concepts that some had previously misunderstood. The various unique VR features coupled with the collaborative learning aspect of iHABS played an important role in effecting this conceptual change. In iHABS, students were able to experience piloting a hot air balloon virtually. This *immersive and direct experience* helped students to understand that the direction of the balloon is fully dependent on the wind and not controllable by the pilot. Moreover, the VR learning environment encouraged students to risk endeavors or experiments that they would not attempt in the real world. One student commented that in iHABS, he was not afraid even if he crashed his balloon in the hills or the sea, and so he was willing to try anything in the virtual learning environment. Thus, the unique feature of VR that enables students to *do dangerous things safely* is certainly an advantage in supporting effective learning. The use of *virtual metaphors* allowed students to visualize the changing values in and the differences between the attributes of the surrounding air and the air inside the balloon. This led to the correct understanding that the greater the difference between the density of the inside and the outside air, the greater the buoyant force: thus, a balloon stays afloat better in cooler air.

The *collaborative strategy* of allocating students to balloons of different size and assigning *specific tasks* to them made the learning process more efficient and effective. Comparing their simulation results for only one round of simulation, we found that students succeeded in understanding that the greater the volume of an object, the greater the ascent rate and maximum altitude; hence, the greater the resultant buoyant force. Without collaboration, they may have had to run the simulation multiple times to acquire this understanding. One interesting observation is that the two students who did not participate in the collaborative activity still held on to the misconception that smaller balloons fly higher. This finding supports the idea that certain physics concepts can be learnt more efficiently through collaborative VR learning. It also provides direct evidence that collaboration within immersive VLEs can aid the process of conceptual change.

Evaluation results from the questionnaire further reinforced the positive findings. 90% of the students commented that VR learning helped them to understand more about the physics of hot air ballooning. One student stated, *"I learnt that there are many factors affecting hot air ballooning, and VR learning presents all of these factors to me."* The students indicated that collaboration did not distract them from completing their tasks.

However, the potential of VR to support deep learning was not established in our study. Only 40% of the students obtained the correct answer to question 5. This result shows that many students still failed to acquire a deeper-level understanding of the physics of hot air ballooning. They continued to hold onto the misconception that the surrounding air generates a net downward force on a volume of air in a balloon. Students could understand that a balloon rises because the outside air density is less than the balloon air density, thus creating an upward force, the buoyant force. However, they failed to grasp that this upward force is actually equivalent to the net force generated by the surrounding air. One possible reason for this outcome may be that abstraction of this deeper understanding requires the development and use of other forms of representation that connect to the experientially grounded immersive learning experience. An approach that can be taken to address this limitation is to design a set of post-VR exercises that would lead students to build upon their ideas further and construct knowledge at a deeper level. Another more active approach that may be effective is to implement a pedagogical agent to play the role of a tutor to prompt students with appropriate tasks and questions at various phases of the simulation to guide them to a deeper understanding of the phenomenon and to help them construct more abstract physics concepts related to hot air ballooning.

6.3 Learning Experience

Our results show that iHABS succeeded in creating an enjoyable and meaningful *user experience* for the students. Most of the students stated that they would welcome repeating the experience. The rating of *sense of presence* was high. All students felt that they were fully immersed in the iHABS virtual world. One student nearly crashed into the sea, but he managed to land just by the water's edge. He remarked that he felt as if he had experienced a narrow escape from death. The presence of avatars representing every student in iHABS further enhanced their sense of presence. Students were observed to be more involved in collaboration after they could see each other in iHABS. In addition, they were truly delighted and excited when they saw each other's balloon flying in the air. The ability to share a virtual environment and its virtual objects obviously increases participants' level of engagement. We also found that students who collaborated well demonstrated a higher sense of enjoyment. Thus, the unique capabilities of collaborative VLEs enhanced students' sense of presence and this, in turn, promoted and enhanced the effectiveness of collaboration within the VLE.

iHABS also succeeded in motivating students to learn more about hot air ballooning. Most of the students agreed that the VR learning process changed their role from receiving information to finding information and applying such information to solve problems. Thus, the constructivist learning approach applied in iHABS provides a reliable basis for a theory of learning in immersive VLES. 90% of the students indicated that the VR learning process helped them to view the physics of hot air ballooning from a different perspective. In addition, 80% of the students indicated that the VR learning process brought out their creativity in solving problems. All these factors contributed to enriching the students learning process. They are clearly an improvement over the traditional approach of instruction-driven learning.

7. Conclusions

Our research work successfully demonstrates the implicit potential of VR to facilitate collaboration. Although strong individual characteristics remain a significant determinant of the effectiveness of collaboration in VLEs, such environments are able to remove the psychological barrier between unacquainted co-learners, and they reduce the negative impact of individual differences between students to some extent. The capabilities of collaborative VLEs in enabling students to see each other, communicate with each other, as well as share virtual environments and virtual objects enhanced their sense of co-presence; this, in turn, enhanced the effectiveness of collaboration.

Overall, the learning outcome of the research study is positive. The unique VR features coupled with the collaborative learning aspect of iHABS played an important role in effecting conceptual change in students on various aspects of the physics of hot air ballooning. Our findings indicated that certain aspects of physics can be learnt more effectively through collaborative VLEs. With the cognitive benefits of articulation, conflict resolution, and co-construction of knowledge, collaboration within VLEs enhanced the students' level of engagement, and this enriched their learning experience.

However, a majority of students failed to acquire the deeper knowledge of physics understanding related to hot air ballooning. Thus, the potential of collaborative VLEs to support deep learning is still not clearly established. More research is needed to derive effective bridging and collaborative strategies to guide students to a deeper understanding of the underlying physics.

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