# Immersive and Non-immersive Virtual Reality System to Learn Relative Motion Concepts

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## Abstract

The focus of the current study is to understand the strength and limits of immersive virtual environments as a new media for learning and teaching relative motion concepts. Our results show that while training in both Immersive Virtual Environment (IVE) and Desktop (non-immersive) Virtual Environment (DVE) resulted in a significant improvement on relative motion problem solving test in general, the IVE group performed significantly better than the DVE group on solving two-dimensional relative motion problems after training in the simulations. This result supports our hypothesis that egocentric encoding of the scene in IVE (where the learner constitutes a part of a scene being immersed in it) as compared to allocentric encoding on a computer screen in DVI (where the earner is looking on the scene from "outside") is beneficial for studying two-dimensional problems.

## Keywords

Virtual Environment, Educational Technology, Immersivity, Relative Motion

## 1. Introduction

In the area of relative motion, a variety of students' misconceptions have been documented. When presented with simple, one-dimensional, relative motion problems, students exhibited widespread difficulties even after completing a unit of relative motion in their physics class [1]. Researchers suggested that these misconceptions stem from a lack of experience with frames of references [2]. Most students do not initially view motion as defined relative to a specific reference frame and frequently do not consider alternative frames of reference besides the default one, which is generally the earth [3-5]. For instance, Ueno et al. reported that in ordinary students' discussions, "static ground" is tacitly considered as a "natural" frame of reference [5]. Furthermore, the idea that stillness and motion are not fundamentally different is particularly counterintuitive [3, 6].

A number of researchers have explored the use of instructional approaches including desktop simulations to address difficulties in learning relative motion concepts. Ziestman & Hewson showed treatment gains in conceptual understanding of relative motion concepts following learners' use of an extreme case in a desktop computer simulation [7]. Mohaghan & Clement analyzed videotapes of the students, half of which interacted with simulations that provided animated feedback while the other half received numeric feedback [2]. The researchers provided evidence that in many numeric conditions students used faulty mechanical algorithms to solve problems, while many animation conditions students used mental imagery to solve problems. In both cases, students modified their approach to relative motion problems when confronted with discrepant events. The results suggest that computer simulations that facilitate dynamic imagery and produce dissonance with previous experiences might be effective for teaching relative motion.

Recently, a variety of three-dimensional (3D) immersive simulations have been applied to different educational domains, and in particular to engineering and physics education as an alternative to conventional non-immersive displays [8, 9]. An immersive virtual environment involves a computer simulation of 3D space and a human computer-interaction within that space [10]. A major characteristics of 3D immersive environments that distinguish them from non-immersive 2D and 3D environments is that they involve egocentric navigation (the learner is surrounded by the environment) rather than exocentric navigation (also referred to as a fishbowl virtual environment) where the learner is outside the environment, looking in [11, 12]. The goal of the present research was to investigate how 3D virtual environments in general and an 3D immersive virtual environment in particular can assist students in learning of relative motion concepts and overcoming their misconceptions.

## 2. Method

Thirty seven undergraduate and graduate students (18 females) majoring in different disciplines (engineering, computer science, information technology, and social sciences) from Norfolk State University (VA) and George Mason University (VA) participated in the study. First, the participants were administered a demographic questionnaire, in which they were asked to indicate their age, gender, major, and the number of physics courses they had taken either in high school or at college level (and, in particular, formal courses where the topic of relative motion had been taught).

Participants were randomly assigned to either Immersive Virtual environment (IVE) or Desktop Virtual Environment (DVE) conditions. There were 19 students (12 females) assigned to IVE conditions and 18 students (6 females) assigned to DVE conditions. All of the students were tested individually.

First, each of the participants was pre-tested with a Relative Motion Problem Solving Questionnaire (RMPSQ) which included 10 one-dimensional (i.e., two objects are moving along one line or two parallel lines) and 6 two-dimensional (i.e. two objects' trajectory were at 90 degrees to each other) relative motion problems sixteen problems designed to assess students' quantitative and qualitative understanding of relative motion concepts. The internal reliability of the questionnaire (alpha Cronbach) is 0.71. The questions were chosen from a number of introductory physics textbooks [13, 14] and modified for the purpose of this study.

After pre-tests, all the participants were exposed to either IVE or DVE virtual simulations on relative motion. The activities in the relative motion simulations in general lasted for 25 -30 minutes. After completing these activities, all of the participants were post-tested on the same relative motion assessment battery they were administered on the pre-test. Finally, all of the participants were given a concluding questionnaire, in which they were asked to describe which aspects of the simulation (either IVE or DVE) were particularly helpful for understanding relative motion, as well as to address any difficulties with the simulation and technical problems.


**Figure 1**: A screenshot from the virtual simulation on relative motion featuring two air tracks.

Both simulations, in IVE and DVE, included the same activities with five levels of increasing complexity. In the IVE environment, the activities were presented to the participants through an nVisor SX60 (by Nvis Inc) Head Mounted Display (HMD). The HMD has a 44″ horizontal by 34″ vertical field of view (FOV), with a display resolution of 1280x1024. During the experiment, participants were placed in the center of the room wearing the HMD. Sensors on the HMD enabled real-time simulation in which any movement of the subject's head immediately caused a corresponding change to the image rendered in the HMD. The participant's head position was tracked by 4 cameras located in each corner of the experimental room and responsive to an infrared light source mounted on the top of the HMD. The rotation of the user's head was captured by a digital compass mounted on the back of the HMD. The student was able to interact with the immersive virtual simulation (i.e., to send different commands) by using a handheld wireless remote control. For DVI condition, the students observed the simulation while looking at a conventional 2D display, and they were able to interact with the simulations using a computer mouse.

Both IVE and DVE activities were based on the same simulation module featuring two air tracks, with one glider on each track (see Figure 1). The module comprises virtual activities with five levels of increasing complexity. In the first three of five levels, the air tracks were aligned parallel to each other, so that students could predict and observe one-dimensional relative motion. Level 1 was an exploratory level, and its main purpose was to allow students to explore and adjust to virtual reality. In levels 2 and 3, students could move (virtually) with one of the gliders while observing the motion of the other glider. In levels 4 and 5, the air tracks were set up at a 90-degree angle, so that students could observe and predict two-dimensional relative motion. Except for the first level, each level included four modes as detailed in Table 1.

**Table 1:** Simulation modes.

| Mode | Description |
|---|---|
| Observational mode | Students could observe the motion of two gliders from a laboratory frame of reference. |
| Prediction mode | Students are asked to predict the velocity of one of the gliders in the frame of reference of the other glider. In the prediction mode students were "lifted up" to a bird's perspective in between the gliders, so that perspective distortion would not obscure their prediction of direction and magnitude (see Figure 2). |
| Verification mode | Students could observe the motion of one of the gliders while virtually "riding" on the other glider |
| Explanation mode | Students could also choose to access an additional mode explaining how to compute the relative velocity |

Students could make turns and watch the scene from different perspectives as well as switch between moving and stationary frames of reference. Arrows indicating predicted and actual relative velocities that were attached to the gliders offered feedback for the students. The developed module has controls and several semi-transparent pop-up menus to adjust virtual world parameters, with high flexibility in parameter settings. Students could start and stop the simulation, and also control when to move on to the next level.

Students could also switch back and forth between a realistic and an impoverished "dark mode" in the virtual lab, in which only the two moving gliders and their relative velocity arrows were visible, to enhance the feeling that the moving glider was a new frame of reference. In addition, a grid moving with the glider (designated as the center of a new frame of reference) was shown to exaggerate the feeling that the moving glider was a new "primary" frame of reference (see Figure 3). The subjects were videotaped performing the activities.

## 3. Results

First, based on the number of formal courses taken where the relative motion topic had been taught (as was indicated in the demographic questionnaire), all the students were divided into two groups, those who received formal instruction in relative motion topics and those who had not. Then we conducted a one-way ANOVA, with prior physics background as a predictor and their scores on Relative Motion questionnaire as a criterion variable, which revealed no significant difference between the two groups of students either on pre-RMSPQ or post-RMPSQ (Fs<1): M=5.11(SD =1.83) for students with no prior physics background, and M=4.75 (SD=2.61) for students with a prior physics background for pre-RMPSQ and M=8.33 (SD=3.67) for students with no prior physics background, and M=8.00 (SD=0.77) for students with prior physics background on post-test RMPSQ.

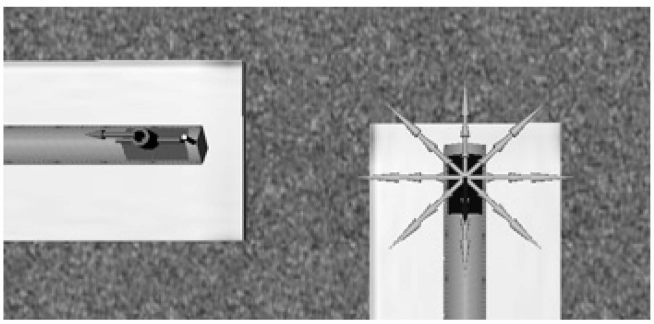

**Figure 2**: A screenshot of the prediction mode.

Second, we conducted a 2X2 MIXED ANOVA analysis with time (pre-RMPSQ and post- RMPSQ) as a within-subject variable and learning environment (DVE and IVE) as a between subject variable. The analysis revealed that all the participants significantly improved their performance on RMPSQ from pre- to post-test: $F(1,35)=32.27$, $p<0.001$. The effect of learning environment was significant $F(1,35) =5.40$, $p = 0.03$ so that overall the IVE group outperformed the DVE group. Follow-up ANOVAs indicated that the IVE group outperformed the DVE group on the post-test [$F(1,35)=5.44$, $p<0.05$], while both groups performed similarly on the pre-test [$F(1,35)=1.83$, $p=0.18$]. However, the interaction between time and learning environment was not significant, $F(1,35) =1.20$, $p = 0.28$.

We found that our participants experienced more difficulties with 2D relative motion problems than with 1D relative motion problems (proportion correct on pre-test = 0.40 and 0.20 for 1D and 2D respectively, and proportion correct on post-test = 0.59 and 0.41 for 1D and 2D respectively). Thus, we conducted analyses for 1D and 2D relative motion problems separately. For 1D relative motion problems, repeated measures ANOVA with time as within-subject variable and learning environment as between-subject variable revealed an overall significant improvement from pre-test to post-test [$F(1,35) =24.30$, $p< 0.001$]. However, neither the effect of learning environment [$F(1,35) =2.52$, $p= 0.12$] not the interaction between time and learning environment ($F<1$) were significant (see Figure 4a). This suggests that for 1D problems both groups performed similarly on both pre-RMPSQ and post-RMPSQ.

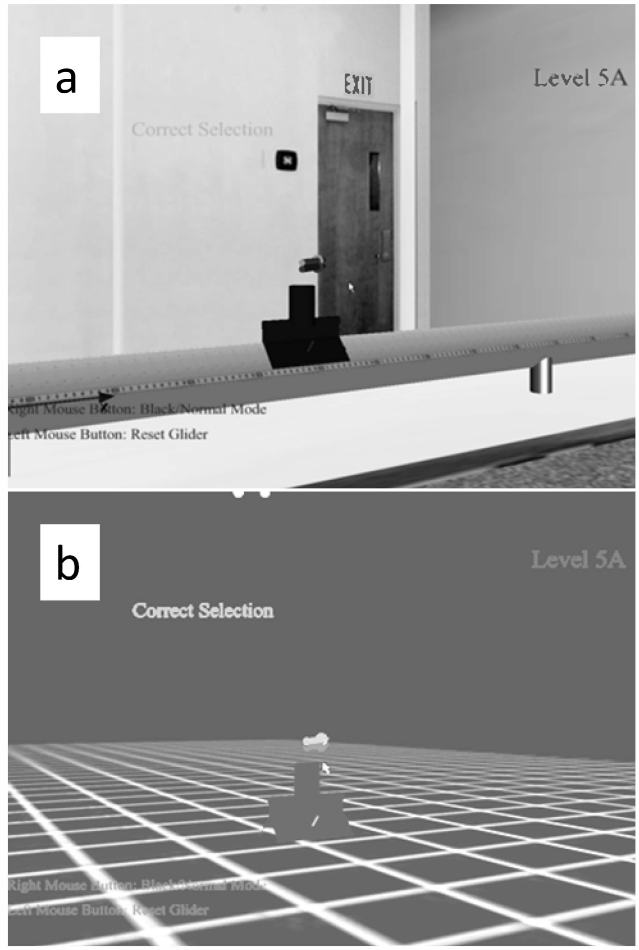


**Figure 3**: (a) Realistic (virtual air-track laboratory) and (b) altered (impoverished dark mode) environments.

For 2D relative motion problems, although the analysis revealed an overall significant improvement from pre-test to post-test for all the participants [$F(1,35) =23.58$, $p< 0.001$], there was a significant effect of learning environment [$F(1,35) =6.63$, $p= 0.01$] and marginally significant interaction between time and environment [$F(1,35) =3.47$, $p= 0.07$] (see Figure 4b). In fact, follow-up ANOVAs indicated that while there was no significant difference between these two groups on pre-test ($F<1$), the difference between them on the post-test was significant [$F(1,36) =10.09$, $p= 0.003$], so that students in immersive conditions outperformed those in desktop conditions on the post-test.

We also analyzed the individual responses on the concluding questionnaire about which aspects of the simulation our participants found particularly helpful in understanding the concept of relative motion and which aspects they did not find useful. The responses were grouped together and are summarized in Table 2.

The simulation was rated by all students as a valuable visualization tool. The use of the impoverished "dark mode" of the virtual lab was reported as a helpful tool for understanding that motion is relative. The possibility of switching back and forth between different frames of reference helped students realize that motion looks different in different frames of reference. It is interesting, that there were more students in the IVE group emphasizing the advantages of "dark mode" and the ability to shift between different frames of reference than in the DVE group, suggesting that these two features are more helpful in immersive virtual reality due to its egocentric visualization.

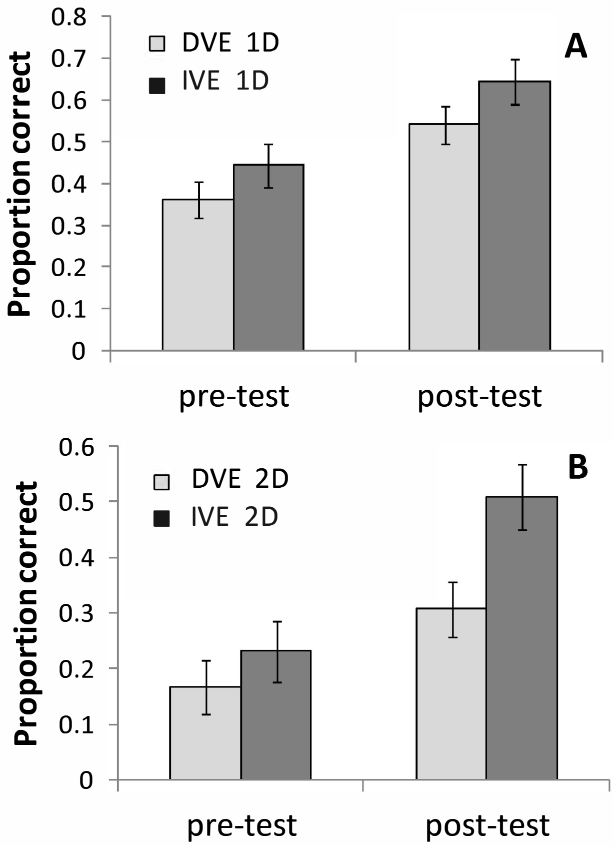


**Figure 4**: Students' performance on pre- and post-RMPSQ. (a) 1D relative motion problems (b) 2D relative motion problems

**Table 2:** Students' reports on helpful aspects of the simulation.

| Helpful aspects | Example of responses |
|---|---|
| General visualization of the environment | S6: ″For whatever reason, I had a much easier time determining relative motion in virtual reality than via pictures on paper.″ |
| Impoverished "dark mode" of the virtual lab | S19: ″Greatly increased my understanding. I could clearly see how the object was moving relative to my movement.″ |
| Switching between frames of reference | S33: ″It showed what I had to imagine in my head. By looking at it, not imagining, it was easier to learn what relative motion is.″ |

Most of the students did not report any major technical or other problems or difficulties with the module. (In fact, 60% of the DVE group and 45% of the IVE group reported that they had not experienced any problems at all.) The only notable concern was one reported by several IVE students that the immersive VR equipment was not very comfortable (e.g., HMD weight, more difficulty in control, etc).

## 4. Discussion and Conclusions

The main goal of this research was to evaluate the potential of virtual simulations in learning relative motion concepts. The findings of this study suggest that carefully designed virtual simulations in either non-immersive or immersive virtual environments improve students' understanding of relative motion concepts. Indeed, students who participated in the simulation activities (both IVE and DVE) exhibited a significant improvement on relative motion problem solving test. Interestingly, there was no significant difference on any of the pre-test measures from the relative motion assessment battery between students with prior physics background and those who had not taken any formal courses in physics, indicating that traditional physics instruction is not effective in eliminating students' naïve beliefs about relative motion. Indeed, as previous research shows, these naive misconceptions are resistant to change as a result of traditional instruction, and require specific visualization tools to foster the generation of appropriate visual models [1, 2].

As was evident from students' reports in a concluding questionnaire, different visualization tools that allowed switching back and forth between different frames of reference and "turning off and on" the laboratory frame of reference ("dark" mode) provided students with new experiences leading to a formation of more advanced conceptual models about relative motion. In particular, as students reported in the concluding questionnaire, "dark mode" allowed them to dissociate themselves from a stationary laboratory frame of reference and observe from a first-hand perspective the motion of other objects from a moving frame of reference (when they were riding on a moving glider). It should be noted, that this experience is more salient in IVE than in DVE conditions. Indeed, recent research in the field of human-computer interaction indicates that a IVE environment encourages the use of viewer-centered encoding, where the presented scene is encoded egocentrically, that is, in relation to the body and the gaze direction of the observer [12]. In contrast, the scene presented on a 2D computer screen is encoded allocentrically, that is, in relation to the standard orthogonal directions or a salient object in the environment such as the sides of a computer screen. These differences in object encoding lead to different perceptions of the objects in a scene.

The "first person" egocentric experience could explain why we found the advantage of IVE versus DVE on the RMPSQ, specifically on solving two-dimensional relative motion problems. Two-dimensional relative motion problems were more difficult than one-dimensional motion problems, possibly because most of the one-dimensional problems were presented in a context familiar to students (e.g., two cars moving toward each other) and thus, were relatively easy for students. Two-dimensional problems, in contrast, required more visualization strategies. While both virtual environments provided an appropriate context not often encountered in everyday life about two-dimensional relative motion, it appears that the IVE observers feel like they constitute a part of an environment in which they are immersed. As a result, they perceive their experiences with objects in IVEs as more realistic (especially if they involve a mental transformation of the observer's body as in the case of visualizing oneself riding on a moving glider) than similar experiences in non-immersive environments where the observer is just observing the scene from the "outside".

In conclusion, the findings of the present study have implications for the designers and evaluators of immersive virtual reality systems on which of virtual reality's features provide the most support for enhancing complex conceptual learning. The results of this study suggest that egocentric encoding of the scene and first-hand experience to change between different frames of reference in IVE (where the learner constitutes a part of a scene being immersed in it) as compared to allocentric encoding on a computer screen in DVI (where the earner is looking on the scene from "outside") can facilitate understanding abstract science phenomena and help in displacing intuitive misconceptions with more accurate mental models.

## 5. Acknowledgment

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## 6. References

[1] J.M. Monaghan and J. Clement, "Use of computer simulation to develop mental simulations for understanding relative motion concepts", International Journal of Science Education, 21, 1999, pp. 921-944.

[2] J.M. Monaghan and J. Clement, "Algorithms, vizualization, and mental models: high school students' interactions with a relative motion simulations", Journal of Science Education and Technology, 9, 2000, pp. 311-325.

[3] C. Camp, J. Clement, D. Brown, K. Gonzalez, J. Kudukey, J. Minstrell, K. Schultz, M. Steinberg, V. Veneman, and A. Zietsman, Preconceptions in Mechanics: Lessons Dealing with Student's Conceptual Difficulties, Dubuque: Kendall-Hunt, 1994.

[4] E. Saltiel and J. L. Malgrange, "Spontaneous' ways of reasoning in elementary kinematics", European Journal of Physics, 1, 1980, pp. 73–80.

[5] N. Ueno, N. Arimoto, and A. Yoshioka, "Learning physics by expanding the metacontext of phenomenon", paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA, 1992.

[6] M. Sequeira and L. Leite, "Alternative conceptions and history of science in physics teacher education", Science Education, 75, 1991, pp. 45-56.

[7] A. I. Zietsman and P. W. Hewson, "Effect of instruction using microcomputer simulations and conceptual change strategies on science learning", Journal of Research in Science Teaching, 23, 1986, pp. 27–39.

[8] S. A. Barab and C. Dede, "Games and immersive participatory simulations for science education: An emerging type of curricula", Journal of Science Education and Technology, 16(1), 2007, pp. 1-3.

[9] C. Dede, "Emerging influences of information technology on school curriculum", Journal of Curriculum Studies, 32 (2), 2000, pp. 281-303.

[10] W. Cockayne, and R.P. Darken, The application of human ability requirements to virtual environment interface design and evaluation, in D. Diaper & N. Stanton (Eds.), Handbook of Task Analysis for Human-Computer Interaction, Lawrence Erlbaum Associates, Mahwah, 2003.

[11] M. Kozhevnikov and A. Garcia, Visual-Spatial Learning and Training in Collaborative Design in Virtual Environments, in X. Wang & J. Jen-Hung (Eds.), Collaborative design in virtual environments, pp. 17-26, Springer, Dordrecht, 2011.

[12] M. Kozhenikov and R. Dhond, "Understanding Immersivity: Image Generation and Transformation Processes in 3D Immersive Environments", Frontiers in Psychology, 3, 2012, pp. 1-10.

[13] J.D. Cutnell, and K.W. Johnson, Physics, John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, 1995.

[14] D. Halliday, R. Resnick, and J. Walker, Fundamentals of Physics, John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, 1993.