

Virtual reality in introductory physics laboratories

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Abstract. Physicists consider laboratories to be a vital part of any introductory course, yet The Ohio State University's existing labs are not meeting their educational goals and students consistently rate them as having low value. This paper explores some of the reasons that standard introductory physics laboratories are not having the expected impact, and describes the implementation of Virtual Reality based experiments to improve upon lab effectiveness. Student response to these experiments and preliminary results regarding their impact on student learning will be discussed.

INTRODUCTORY LAB PROBLEMS

Physics laboratory (lab) activities have the potential to achieve a variety of goals and provide a valuable enhancement to introductory courses [1]. The current labs at The Ohio State University (OSU) utilize Socratic [2], Physics Education Research (PER) – based manuals aimed primarily at improving student conceptual understanding. Although initial reports [3] indicate these labs improved student gain on the Force Concept Inventory (FCI) [4], currently observed FCI gains are lower, and comparable to traditional courses [5]. In addition, OSU students often rank these labs as the least helpful component of the introductory physics course [6].

Before implementing enhancements to the labs, it is necessary to gain some idea of problems with the existing labs. The lab manual contains exercises which can be quite good at improving conceptual understanding, but this depends on how students approach the labs. Although the following problems are speculation, they have been observed by the authors as well as several of the lab instructors. We feel it is likely these problems are common, and are not specific to OSU.

Although some lab programs explicitly address error analysis as part of the experimental process, the existing OSU labs do not. It is documented that students have difficulty carefully addressing error even when emphasized during the lab [7]. Student comments indicate they think error is “bad”. This can lead to frustration, or worse: students ignoring inconsistencies with predictions by blaming them on experimental error. We often implicitly expect

students to ignore effects such as friction, while observations under incorrect assumptions may lead to wrong conclusions. Due to the unfavorable instructor-student ratio in large introductory service courses it is often difficult to address these issues properly.

The OSU lab questions are aimed at addressing common conceptual difficulties and when not carefully considered can appear simplistic to our students. They are sometimes overconfident, thinking they already “know” the concepts from attending lecture and reading the text. Many students are also reluctant to do the labs carefully, believing the lab activities will not help them with their exams. In reality, low FCI gains show that students are missing fundamental physics concepts, which is not only disturbing for instructors, but should be important to students, since an unstable conceptual foundation can lead to mistakes on graded work.

Physics Education Research has shown that active engagement computer-based activities are more effective than passive programs [8-10]. FCI gains have been shown to improve significantly with the replacement of a single traditional lab with a PER-based activity [11]. However, even effective computer-based activities can sometimes lead students to view the computer as authoritative [12], with information output accepted as fact without critical consideration. Virtual Reality (VR) software developed at OSU has the potential to improve upon problems associated with OSU's existing labs. In addition, VR can be fun and engaging to students, and could even improve their overall attitudes towards physics [13].

VIRTUAL REALITY TO THE RESCUE

The PER group at OSU has developed a VR platform that can run several VR-based experiments. These allow students to view processes in a much more detailed and controlled way than is possible with traditional equipment. Parameters can be easily adjusted for careful exploration of phenomena, providing more freedom to choose what conditions to test. Friction can be turned off and on to allow students to carefully observe how motion is affected. Processes that are normally too fast to observe can be run in slow motion, revealing details students might otherwise miss. VR can accommodate both very large and very small scales, allowing for a more detailed study of a process.

This virtual environment is manipulated using a touch-sensitive joystick; if the student pushes harder a larger force is applied to the object in the simulation. This allows students to apply a controlled force at a distance and instantly see how their force affects the motion of an object. Unlike typical computer-based activities, the VR output is not authoritative information; it is a direct, real-time response to student input. This provides a true complement to traditional lab experiments.

The VR platform is engaging. The viewpoint moves with the object of interest through scenery. Many students enjoy video games, and the VR scenery and joystick mimics them. Students often challenge each other to see who can best control the motion of an object, or see if they can cause some strange effect to occur. These voluntary explorations give them added experience with Newton's laws. Although we encourage this and enjoy the exploratory attitude of the students, all VR activities are written with a sequence of prediction, testing, and resolution of differences to maximize the educational impact of the VR features. Because this platform is seen as fun by many students, concepts can be repeated with lower student resistance than in a traditional activity.

THE THREE NEW VR LABS

Three VR programs were ready for full implementation at the start of this investigation; those dealing with linear motion, circular motion, and collisions. Each of these was incorporated into a new lab for OSU's introductory calculus-based mechanics course spring quarter.

The Linear Motion VR lab

The Linear Motion VR lab allows students to probe Newton's 2nd law using the Linear Motion VR software (Fig. 1). A box rests on a scenic track, and the students can apply an external force to the box using a joystick. All parameters are adjustable: the initial conditions, the mass of the block and the coefficient of friction. The force diagram for the box can be displayed in real time, in addition to vectors representing the velocity and acceleration of the box. Motion graphs can also be displayed on the screen.

The current OSU linear motion lab falls short of the full time period. Therefore, we implemented this software by integrating questions requiring its use into the existing lab. In this way, students made predictions and observations of the motion of a cart with external forces applied, and then further explored Newton's 2nd law using predictions and observations through the VR environment.

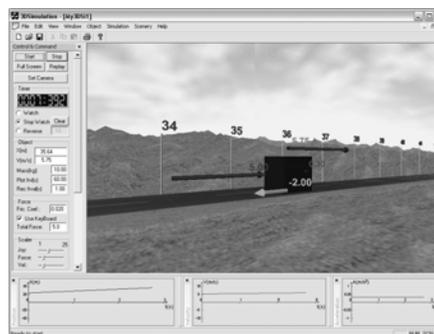


FIGURE 1. The Linear Motion VR program

The Circular Motion VR lab

Before now there has not been a circular motion lab in this course. The new Circular Motion VR lab (Fig. 2) contains a ball and a circular track. The initial conditions of the ball can be set and the external force, velocity, and acceleration vectors can be displayed. The object of the program is to apply external force with the joystick to keep the ball in uniform circular motion. This can be done with and without friction.

Even if students had studied central forces in lecture and predictions were made prior to using the VR, students often first tried to drag the ball around the track. This instinct is then better understood and corrected when the experiment is repeated with friction turned on. In addition to the VR software, students were given a small smoothly rolling ball and

a rough puck to contrast with the motion observed using the computer.

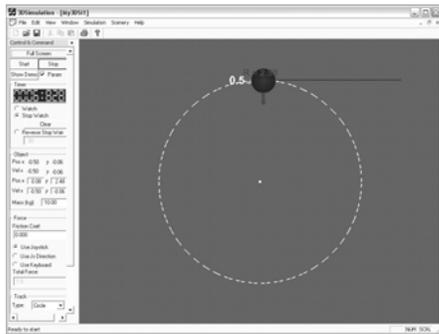


FIGURE 2. The Circular Motion VR program

The Collisions VR lab

The Collisions VR program (Fig. 3) contains two carts on a scenic track. All initial conditions can be adjusted for each cart. The user can also set both the coefficient of friction and the elasticity of the bumpers. As with the Linear Motion VR program, the force diagrams, velocity and acceleration vectors, and motion graphs can be displayed in real time.

Although there is normally a lab covering collisions at OSU, a completely new lab was written following the suggestions in [14]. The VR software permits a detailed exploration of the forces acting on each cart during the collision, permitting an approach to conservation of momentum directly from Newton's 3rd law. During one lab period, students were able to predict and observe the forces while a cart collides with a wall, a spring, another cart moving towards it, and another stationary cart. Many other interesting combinations are possible, including collisions between carts of very different masses, initial speeds, and/or elasticity. Students sometimes explored these on their own at the end of class.

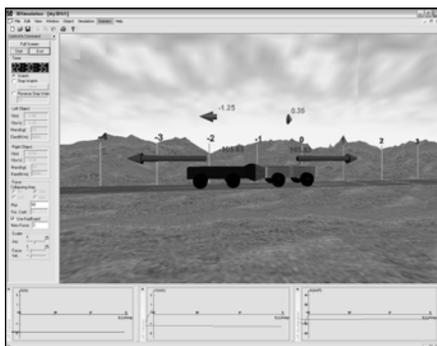


FIGURE 3. The Collisions VR program

WERE THE VR LABS EFFECTIVE?

In order to test the effectiveness of the new VR labs, students were given the FCI during the first and last lab period. In addition, students were given a set of nine questions written to test their physical intuition about how force affects motion. In order to determine the effect of the VR labs on student attitudes, a qualitative questionnaire was also given.

The introductory calculus-based physics students were split into two groups, referred to as the Linear VR group and the Collisions VR group. The Linear VR group, containing 136 students, did the new Linear Motion VR lab and the existing collisions lab. The Collisions VR group, containing 118 students, did the new Collisions VR lab and the existing linear motion lab. Each group served as the control for the other group and both did the Circular Motion VR lab. The two groups were shown to be statistically similar based on their FCI pretest scores. None of the lab instructors were involved with developing the VR labs, nor are they involved in PER.

Looking at the normalized gains (as defined in [5]) for specific questions on the FCI, a significant difference was seen for questions that corresponded to the activities performed in the VR labs. The Linear VR group had a gain of 0.35 on FCI questions 25 and 26, which directly relate to activities done with the joystick, while the control group gain was only 0.23. It is significant to note that the FCI posttest was given a full 6 weeks after the Linear Motion lab. The Collisions VR group had a gain of 0.38 on FCI questions 4, 15, 16 and 28 pertaining to Newton's 3rd law, while the control group gain was 0.26. This second result is also partly due to the completely different structure of the new VR lab. Similar results were seen with the nine extra questions which will be addressed along with a more detailed quantitative analysis of our results in a longer publication to follow shortly.

In a multiple-part qualitative feedback question we asked the students if they preferred existing labs or the VR labs. We asked 4 sub-questions spanning from educational impact to level of enjoyment. The students had a slightly higher overall preference for the VR labs. This result is very encouraging when considered along with the fact that when asked which individual lab the students like best and why, students strongly prefer a subset of the existing labs called experiment problems. In these labs, students design their own experiment for determining an unknown quantity. In fact, all three experiment problems ranked in the top four (also included was

the Collisions VR lab). This means that despite the students' strong preference for the experiment problems, half of them would still rather have VR labs than existing labs.

Students were asked to give specific feedback as to their preference between VR and existing labs. The majority of students who prefer the regular labs state that it is because they like having something hands-on (21%) or "real" (11%). The majority of students who prefer the VR labs state that it is because there is "no error," the environment is "exact" (19%). These students would best make use of a mix of physical experiments and VR experiments to directly contrast ideal with real. Some representative student comments on the VR labs are given in Fig. 4.

Some Student Comments Regarding the VR labs:

- They are a great complement (to regular labs)
- Allows us to see the inner workings of a system
- There is more control over the environment
- It gave instant data feedback

FIGURE 4. Student Comments

Students were asked if using the joystick helped them get a better feel for how force affects motion. 95% of the students doing the Linear Motion lab found the joystick more helpful than traditional lab equipment. Among the 19% of students who ranked the VR labs low, 31% of them attributed their ranking to technical reasons, such as "the joystick was hard to control" and "the software was difficult to use". These drawbacks will be improved before our next implementation.

Lab instructors felt that the new VR labs challenged the average student and were more interesting than existing labs. They observed a higher level of interest and excitement when the students used the VR as compared to the traditional lab equipment. We hope the students came away with a better attitude towards physics, which is a topic being further explored in our research.

CONCLUSIONS

This paper discussed the motivations for implementing VR labs in the introductory calculus-based mechanics course at The Ohio State University (OSU). Existing labs are not meeting their educational goals and are not seen as a valuable component of the course by students.

Three VR-based labs were implemented to help enhance the existing labs. Students doing the new labs scored higher on specific FCI questions which were most related to the VR activities. Students responded positively to the VR labs stating overwhelmingly that the joystick was more useful for understanding forces than the normal lab equipment.

Although students were mixed as to their preference of VR over existing labs, there is strong evidence that students would value having a mix of both types. Progress is being made towards combining the VR experiments with traditional lab equipment. This provides the students with both the hands-on and ideal environments they enjoy while possibly improving their conceptual understanding.

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