An Example of Virtual Reality Experiments in Introductory Physics Laboratories

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Abstract:

- The Ohio State University (OSU) Physics Department is modifying the current introductory calculus based Physics laboratories to include Virtual Reality (VR) experiments developed by the PER group at OSU. The new laboratories combine physical equipment which gives hands-on experience with simulations which provide an ideal environment for studying specific processes in detail. The VR experiments allow for detailed study of fast processes which otherwise would not easily be visualized. An example of this is the new Impulse-Momentum laboratory. The VR collisions software shows the forces and resulting deformation of two carts during a collision. This leads to student exploration of momentum conservation directly from Newton's third law. Students not only confront cognitive conflicts about forces but also develop a deeper understanding of momentum conservation. This poster will present the value of incorporating VR simulations with specific examples from the Impulse-Momentum laboratory.

Overview:

- Why implement Virtual Reality (VR) labs?
- How the VR labs were tested and implemented at OSU
- An example of a specific VR lab and how it was developed
- Preliminary results regarding the value of implementing VR labs

Why implement VR labs?

- The VR environment can be fully controlled – all parameters are adjustable
  - This allows for careful exploration of phenomenon as many modifications of an experiment can be tested quickly to differentiate cause and effect
  - Parameters such as friction can be turned off and on allowing students to clearly contrast the resulting behavior and carefully consider the meaning of the physics laws under study
- VR allows for the study of things not easily possible with traditional equipment
  - Fast processes can be slowed down
  - Very large and very small scales can be observed

Why implement VR labs (continued)?

- Using a joystick mimics playing a video game, which prompts students to use the VR
  - Students will repeat exercises using VR because they are fun – this may help them catch possible misconceptions
  - Students often challenge each other to see who can best control the motion of an object, or try to get a strange effect to occur – this can add to the learning experience
- VR is fun and engaging
  - This can improve student attitudes towards labs and may also improve student attitudes towards physics
  - This can lead to increased learning by the students

Implementing and testing the VR labs:

- Three VR programs were integrated into the introductory calculus-based mechanics lab at OSU during spring quarter, 2004
  - Four groups of students tested this lab during the development phase the previous quarter to check for clarity, length and difficulty level
- The VR implementation ranged from additional exercises given along with the traditional lab, two completely new labs like the one discussed in this poster
- Students were split into two groups, each group did a new VR lab one week, and the traditional lab the other week – thus each group acted as a control for the other group
  - Both groups did the third lab since it did not correspond to any of the traditional labs for this course

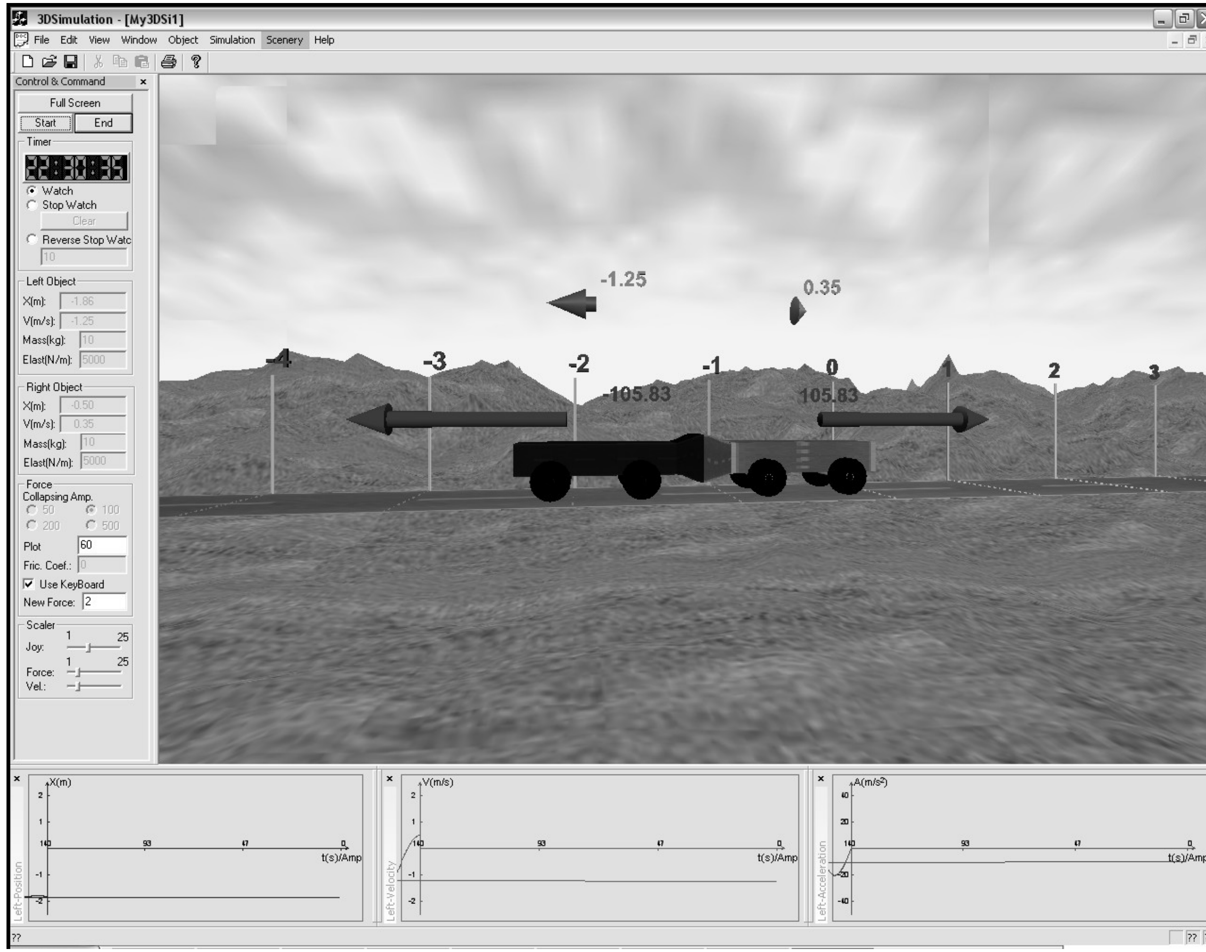
Development of a new lab using the VR software:

- The Collisions VR software has been developed for students to study impulse and momentum
- The program makes effective use of the VR technology by:
  - Slowing down the collision for a more careful look at what occurs
  - Modeling of the forces and resulting cart deformation which occurs during the collision in real-time

Details of the Collisions VR software:

•The initial conditions, the coefficient of friction and the elasticity of the bumpers can be set by the user

•The force diagram, velocity and acceleration vectors, and motion graphs for both carts can be displayed in real time



Screen shot of the Collisions VR interface

Structure of the new Collisions VR lab:

- Since the VR software clearly shows the forces occurring during the collisions, an approach to understanding momentum conservation directly from Newton's 3rd law can be used:
  - Students realize that the forces the two carts exert on each other belong to a Newton's 3rd law force pair
  - Students see that the collision time is the same for both objects
  - Students calculate and compare the impulse exerted by each cart on the other cart
  - Students see that momentum must be conserved for each type of collision
  - This method is motivated and explained in the book "Five Easy Lessons, Strategies for Successful Physics Teaching" by R. D. Knight

Some interesting collision possibilities:

- Students can explore a variety of interesting collision types including:
  - A cart colliding with an initially stationary cart
  - A cart colliding with an initially moving cart
  - Two carts of different initial speeds colliding
  - Two carts of different masses colliding
  - Colliding two carts with different bumper elasticity

Specific questions from the Collisions VR lab:

- Students first work through an experiment similar to the one which follows, except using a cart colliding with a spring. This case is easier for the students to analyze, and provides the necessary basis for carefully considering the more difficult problem below.
- We have in front of us two carts on a track. The mass of each cart is approximately 0.5 kg. In this experiment we will push the carts towards each other with equal initial speeds and observe the resulting collision.
- On the left, draw the force diagram of cart 1 during the collision (while it is in contact with cart 2). Be sure to label each force clearly. On the right, draw the force diagram of cart 2 during the collision (while it is in contact with cart 1).

Specific questions from the Collisions VR lab (continued):

- Of the forces you included in the above two diagrams, are any of the ones in the left diagram the same in magnitude to any on the right diagram? From Newton's third law, do you expect any of them to be?
- How does the collision time for cart 1 compare to the collision time for cart 2?
- Predict and make a rough sketch for how you expect the force of cart 2 on cart 1 to vary throughout the collision. Explain why you drew your force curve the way you did.
- Predict and make a rough sketch for how you expect the force of cart 1 on cart 2 to vary throughout the collision. Explain why you drew your force curve the way you did. Is it consistent with your previous answers?

Specific questions from the Collisions VR lab (continued):

- Describe the motion of each cart at the peak of their force curve, what is happening to each cart at that precise point?
- Using the equation for impulse, how does the impulse given to cart 1 by cart 2 compare to the impulse given to cart 2 by cart 1?
- What does this tell you about how the change in momentum of cart 1 compared to the change in momentum of cart 2?
- What then can you conclude about the total change in momentum of the system?
- Can you make any general conclusions about the change in momentum for any collision? (Consider the above analysis, what will change for a different type of collision, what will be the same?)

Specific questions from the Collisions VR lab (continued):

- At this point in the lab the students are asked to contrast their diagrams and answers with observations made using the VR program.
- Graph of the forces on each cart are plotted in real time during the VR collision by the software. With this data, students can make a numerical estimate of the impulse and compare it to the change in momentum of each cart.
- Students also test the collisions using carts on a track and two motion detectors.

Specific questions from the Collisions VR lab (continued):

- Students can then explore more difficult cases, such as colliding two carts of unequal initial velocity.
- Students have difficulty with applying Newton's 3rd law to dynamic collisions, and typically need assistance in the initial phases of the experiment. By the end of the lab, however, they show a far better understanding of the forces which act during the collision.
- This helps students better understand Newton's 3rd law and internalize the idea that momentum is conserved in every collision

Preliminary results:

- The Collisions VR group had an average 46% higher normalized gain on FCI questions 4, 15, 16 and 28 pertaining to Newton's 3^{rd} law
  - This result may very well be caused in part by the completely new structure of the VR lab, and not just the VR software
- Students indicate a strong preference towards having a mix of physical experiments with VR experiments to maximize the usefulness of labs
- Many students voluntarily suggested that increasing the amount of VR labs would be a good way to improve the course
- Lab instructors noticed a higher level of excitement in the students when they used the VR equipment

Conclusions:

- A combination of hands-on with virtual experiments may be a valuable improvement to traditional labs
  - A wider variety of activities can be explored, and features of VR allow for careful contrast of observations which may lead to better understanding of fundamental physics laws
  - Students show a strong preference for this, thus increasing student interest and involvement in the lab activities
  - Preliminary results show that this is an effective method for increasing student understanding