VIRTUAL WORLDS AND THEIR ROLE IN INVESTIGATING CHANGE IN COGNITIVE MODELS OF MOTION

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Abstract

There is considerable preliminary evidence that virtual environments are highly effective for allowing participants to internalise data and acquire new understanding. However little principled empirical work appears to have been carried out on the effectiveness of virtual reality in environments for such purposes. A systematic approach is explored to the study of the effectiveness of virtual environments for studying change in students' mental models of motion.

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D. Whitelock and S. Holland

1 INTRODUCTION

Previous research into children's ideas about physical phenomena has shown that these ideas are very different from those of the scientist. There is a large body of research data, mainly descriptive accounts of children's reasoning, which is not always easy to interpret. (For extensive overviews see Driver and Erickson (1983) and Gilbert and Watts (1983)). There is also a difference of opinion about how these conceptions should be viewed: it is not clear whether children's ideas in dynamics should be described as systematic mental structures or as ad hoc temporary constructions.

Following the work of McCloskey (1983) and Whitelock et al (1989) it is our belief that commonsense ideas about motion can be represented as causal models which are different from the Newtonian view of motion. Students' failure to answer dynamics problems correctly (as demonstrated by Caramazza et al 1981; Clement 1982; diSessa 1985; Larkin et al 1980; McDermott 1984; McCloskey 1983; Viennot 1979; White 1983 and many others) reveals a lack in their knowledge of the causal principles that underly the formulas they have been taught. We believe that experiences that enable students to acquire accurate causal models will make them less likely to develop misconceptions, and better able to understand the principles underlying Newtonian mechanics.

We hypothesise that a sequence of pre-designed activities carried out in a virtual environment with a head-tracking head-mounted display and a dataglove will lead students to build up an accurate qualitative model of the laws of motion more effectively than conventional computer simulations or instruction using physical apparatus such as found in schools. We propose to build a collection of virtual worlds designed to aid particular stages of acquiting accurate causal models of motion. In order to understand the prima facie evidence for our hypothesis, we need to consider theories of how commonsense conceptions of motion arise.

2 WHY DO PEOPLE HAVE TROUBLE LEARNING DYNAMICS?

People have difficulty understanding dynamcis, even undergraduates and post-graduates (Viennot 1979; McCloskey 1983; diSessa 1985) and their misconception are diffiuclt to change. Evidence suggests that people use a non-Newtonian framework to understand motion.

McCloskey's work (1983) led him to suspect that intuitive beliefs about motion play a role, not only in people's thinking about hypothetically moving objects, but also in their interaction with moving objects. These intuitive beliefs "appear to be grounded in a systematic intuitive theory of motion that is inconsistent with fundamental principles of Newtonian mechanics". In order to investigate systematically the relation between beliefs and actions, McCloskey devised two types of tasks to see if intuitive ideas about motion might influence how high school and college students performed the tasks. One of the task was to investigate, through actions, intuitive beliefs about the motion of dropped objects. The other task was to investigate subjects' ideas about circular motion. Subjects were asked to push a small object across a table so that it would pass through a 90 degree segment of a large circular ring-shaped area marked out on a table.

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In the first task, undergraduate students were asked to walk across a room and while they were walking to drop a golf ball so that it would hit a target marked on the floor. On 45% of the students acted as if they knew the ball would travel forward as it fell. 49% acted as if the ball would fall straight down and land immediately below its point of release, while 6% acted as if the ball would move backwards as it fell.

In the second task, 25% of the subjects moved the puck in a curved path before releasing it, appearing to believe that it would continue to curve after release and so would follow the arc of the ring segment. These subjects were surprised when the puck failed to curve.

McCloskey suggests that the undergraduates viewed circular motion as not being fundamentally different from motion in a straight line. Both forms of motion are generated by imparting the appropriate impetus to an object. However a pupil working with a Newtonian framework would realise that for an object to move in a circle, it must be acted on constantly by an outside force that tends to deflect the motion from linearity.

McCloskey's methodology is an important and useful contribution to our understanding of subjects' intuitive ideas in dynamics. He believes there is some structure to these intuitive notions. His studies suggest that students' errors are systematic, and he remarks that their intuitive theory bears a striking resemblance to the pre-Newtonian theory of impetus (an idea previously proposed by Viennot). His technique has removed problems of mathematical manipulation, interpretation of graphical data and diagrams from the understanding of the problem. There are, however, difficulties in adopting an historical model to describe spontaneous reasoning in dynamics, in that the model does not account for all the different responses found in the literature.

A formal model of commonsense understanding of motion based on work by Whitelock, Ogborn and Bliss (Bliss et al, 1989) and further developed by Whitelock (1990) gives a causal structure to this framework, and predicts that commonsense ideas about motion will be highly resistant to change by abstract argument or presentation. However, the model suggests that in environments where the effects of gravity, air resistance and friction, etc. can be varied, directly experienced action upon objects could lead to changes in deeply held commonsense understandings of motion. The model seeks to look for the primitives of reasoning about motion and suggests that an understanding of motion is achieved by constructing a class of stereotypical motions from a set of primitive actions. These include SEE/HOLD, LET GO and MOVE YOURSELF. Piaget proposed that during the sensorimotor stage the child uses primitive actions to construct the motion of object, time, space and causality, i.e. to construct a commonsense theory of motion. Therefore if such actions can be performed on objects in environments where gravity, air resistance, friction, etc. can be varied, this could lead to changes in deeply-rooted intuitive conceptions of motion. A Virtual Reality Environment provides the only practical means to perform such an experiment.

3 PILOT RESEARCH AT THE OPEN UNIVERSITY.

O'Shea and others (Twigger et al, 1991) have developed a two-dimensional software system known as DM3 (Direct Manipulation of Mechanical Worlds) in order to help children reflect critically upon and modify their own conceptions of the laws of motion. O'Shea and others (Taylor et al, 1991) have also been involved in the educational evaluation of ARK (the Alternative Reality Kit), a two-dimensional computer-based environment in which the laws of physics can be modelled and altered. While these environments have shown some success in helping children articulate their own notions of the laws of motion, it is not yet clear the extent to which they help children to from stable, accurate, causal models of motion. White and Horovitz (1988) carrying out similar work in American schools report some success, but it has proved difficult to produce similar results to date in the UK.

There is evidence to believe that an environment that engendered a stronger sense of physical involvement and presence might do considerably better. Virtual reality differs from two dimensional computer simulations in at least three important ways; its use of three dimensions: the very high degree of sensorimotor interactivity: and the compelling sensory cues that engender a strong subjective sense of "physical presence" and "direct experience" (Zeltzer, 1990). The importance of this subjective feeling of sensorimotor immersion can be seen by reference to theories of how commonsense conceptions of motion arise.

We have already noted Whitelock's (1990) formal causal model of commonsense conceptions of motion, based on the psychological primitives of "support" and "effort". This theory suggests that commonsense conceptions of notion are acquired through early sensorimotor activity, and that while they are highly resistant to reasoned argument, exposure to new sensorimotor experiences, in which objects can be thrown and played with in the apparent absence of gravity and friction, may give rise to changes in these conceptions. However, it is not known the stages by which such conceptions might change, or exactly what their new nature would be. Investigations are needed to discover the extent that commonsense notions can be effected by new experiences not normally possible in the real world, and the extent to which such comceptions will be transferable to the real world.

4 RELATION TO OTHER VR WORK

Reviews of work on virtual reality environments can be found in Brooks et al (1988,1990) and Chung et al (1989). Existing virtual environments which allow professionals to internalise large amounts of data rapidly include work on: headmounted displays and gloves for information management (Fisher et al, 1986); the GRIP and GROPE systems for interactive molecular studies (Chung et al, 1989); the Walkthrough Project (Brooks, 1986) for virtual building exploration; and work by Iwata (1990) , Weimer and Ganapathy (1989) and Waldern and Edwards (1985) with applications in industrial design. Kreuger (1990) and others have written speculative papers on the use of virtual reality in education.

One of the few virtual environments (using a different technology from our proposal, with force-feedback) that has been systematically used and evaluated for education and research is GROPE, due to Brooks et al (1990), for work in protein docking and electrical force field investigation. Users reported a radically improved situation awareness and a new understanding of receptor sites, force fields and drug docking. Unexpected perceptual phenomena were observed, all of which worked in favour of the effectiveness of the tool. There is considerable preliminary evidence that virtual environments are highly effective for allowing participants to internalise data and acquire new understanding. However, little principled empirical work appears to have been carried out on the effectiveness of virtual reality environments for such purposes. The proposed work would be one of the first systematic studies of the effectiveness of a virtual environment for teaching.

5 PROPOSED VIRTUAL WORLD TUITION

We propose that students should undertake activities in four related microworlds. (Their physics understanding as a result of their experiences will be measured with performance scores on a pre and post test). The group using the virtual environment will be invited to undertake activities in four related virtual microworlds. They will intitially be given time to acclimatise to the equipment and to each new virtual world. The domains covered are (a) projectiles in zero gravity with no air resistance or friction, (b) experience of relative motion (c) motion of projectiles under gravity (d) motion of projectiles with speed-dependent air resistance.

The first microworld is designed to help develop an intuitive familiarity with Newton's first law. This environment will simulate the effects of zero gravity without air resistance or friction. For their first task in this world, students will be set the (impossible) task of throwing projectiles in such a way that they follow curved paths. This microworld also permits comparison between motion of projectiles of different masses with impulse rockets attached. The size or number of impulses can be contolled. As in all of the microworlds, projectiles may be set to flash at regular intervals, which causes them to leave 'tracer' trails in space. There will be a facility for traces to leave projections on reference x, y, z, planes.

Students may examine the traces from different viewpoints, and may uniformly copy, shrink and keep traces for subsequent comparison, so that speed-time graphs may be produced.

The second microworld is concerned with relative motion. Students are initially invited to 'drive' in a vehicle toward a given distant target, acoss a platform moving at right angles at uniform speed. They are invited to predict how their trails will appear from the point of view of an observer on the moving platform, and from the point of view of an observer at rest with respect to the stationary target. Other possible activities in this microworld might involve a platform that moves with uniform acceleration, and space ships in relative motion in three dimensions. The tasks in this microworld are designed to develop an intuitive sense of how relative motions combine when viewed from different frames of reference. It appears to be difficult to foster a good subjective sense of relative motion using conventional two dimensional computer simulations (Whitelock et al 1991), although we suspect such a sense may contribute greatly to the understanding the motion of projectiles under gravity.

The third microworld is similar to the first, but introduces gravity, which may be varied in strength. The motion of projectiles of different masses may be compared when thrown or fired, using rockets. The fourth microworld is an extension of the third, allowing 'gases' to be introduced to provide different air resistances. The motion of projectiles of different masses may be compared when thrown or fired using rockets against air resistance. Comparisons can be made in the final microworld with gravity on or off. The exact form of these microworlds may be adjusted or refined before the formal experiments, subject to experiences in the informal pilot stage during development.

We are aware that the Virtual Worlds Simulation will be far from perfect. The different mass and weight of projectiles will not be directly felt. Whole-body acceleration forces will not be simulated. Students will feel the effect of gravity of their own bodies. However our own preliminary experiences in virtual worlds, suggest that the combination of perceptual effects that are well-simulated by the apparatus will be strong enough to give rise to the effects that we hypothesise.

6 CONCLUSION

There is considerable preliminary evidence that virtual environments are highly effective for allowing participants to internalise data and acquire new understanding. However little principled empirical work appears to have been carried out on the effectiveness of virtual reality in environments for such purposes. The proposed work would offer a systematic study of the effectiveness of a virtual environment for studying change in students' mental models of motion.

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