Promoting conceptual change in children learning mechanics

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Abstract

We will describe an attempt to improve children's understanding of some basic concepts in mechanics starting from an examination of their ideas of motion. Children's personal experience of the world colours their beliefs and explanations in science. A computer augmented curriculum was designed to promote conceptual change in the classroom. Twenty-nine twelve- and thirteen-year-olds, and their usual classroom teacher tried it out. The computer programs consisted of interactive simulations which allowed direct engagement with animations of real world scenarios in which pupils have control over forces and objects. We demonstrated that this curriculum produced evidence of conceptual change. Our findings have implications for the development of a more sophisticated view of conceptual change.

Introduction

We are reporting on a three year project[1] on promoting conceptual change in Science. This project was designed to examine the process of conceptual change and to develop and test ways in which such change can be achieved using computer tools in classroom situations. An experimental curriculum (occupying thirty hours of class time) designed to teach mechanics concepts to twelve year olds was developed. We have described some of its features e.g. the identification of the prior conceptions which influence children's learning in mechanics, the design of four scenarios which underpin the sequencing of the material taught, the use of specially created software designed round these scenarios and integration of the computer experiments with "real practical experiments" in Twigger et al (in press), and Hennessy et al(in pressa.) The classroom evaluation produced some interesting results which have implications for teachers of science (O'Shea et al, in press). Our plans to design and use software tools were influenced by two previous pieces of work - ARK, the Alternate Reality Kit designed by Dr Randall Smith and the work on modelling tools like STELLA. Our research hypothesis was that using these computer tools would promote conceptual change in science because they require children to make their reasoning explicit or that they enable them to visualise of the consequences of that reasoning. Also, the computer provides representations to be used as bridging analogies, or devices to follow the progress of interactions. For example simultaneous

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recordings of experiments which can be replayed and studied. Our simulations have three important features:

- their use of alternate realities,
- their use of direct manipulation software,
- their integration of these computer experiments with "real" experiments.

Previous experiments with ARK (Scanlon and Smith, 1988, O'Shea et al, 1990) demonstrated that the ability to perform experiments where students could see the effect of the laws of physics being otherwise had enormous educational potential.

Having chosen a particular topic area, viz, force and motion, we conducted 'clinical' interview and paper an pencil studies with thirty six children between the ages of ten and fifteen with the aim of identifying common prior conceptions in children's ideas about horizontal and vertical motion. We investigated whether these conceptions were age dependent (Twigger et al, in press). Our next task was the design and implementation of the software environment. We constructed prototype screens and tested these prototypes with groups of children to remove any interface or representational problems (Hennessy et al, 90). Then we developed the computer curriculum which incorporated four scenarios chosen to address specific concepts identified as problematic in the interview study. These computer simulations together with the associated worksheets and test items were then pretested with groups of children of our chosen age of twelve, before the final stage of the project. The curriculum materials depended not only on the simulations but with integrated "real" as opposed to computer based practicals. This final stage involved the curriculum being presented over a seven week period by the teacher of a class of 29 twelve year olds, using five computers located in her laboratory.

Identifying prior conceptions

We focused on mechanics as our topic area, so that we could build on previous work on children's prior conceptions, by Ros Driver and others (Driver, 1984, Driver, Guesne and Tiberghien, 1985).and reviews of the research into prior conceptions about aspects of force and motion (McDermott, 1984, Gunstone and Watts, 1985 and Halloun and Hestenes, 1985). We decided to investigate the dynamics reasoning of students aged 10 to 15. We were particularly interested in common prior conceptions about aspects of vertical and horizontal motion, and whether these were age dependent. Seven tasks which covered a range of dynamical contexts including, motion on the horizontal as a result of an impulsive force, constant motion on the horizontal with friction, accelerated motion on the horizontal, free fall motion (with air resistance) and projectile motion were used with pairs of students taking part in an hour long interview. Individual students then wrote answers on their own personal response sheets. A number of features of students conceptualisations of forces and motion were identified. Our pupils had the idea of a "force" which gets given to an object when it is pushed or thrown. As an object moves along, this "force" gets used up, and when it is completely used up the object stops. Most pupils do not seem to have the idea of of friction as a force opposing motion, though some have the idea of 'grippiness' between surfaces which is related to weight. Pupils make incorrect predictions based on their alternative models of phenomena e.g. they predict that an object continues to speed up in situations where it wouldn't. Also, pupils predict events correctly but explain them incorrectly by using their alternative models, e.g. they reason that a forward force must be greater than friction when an object is moving at constant speed (embodying the 'motion requires force' model). Pupils also had problems with symbolic representation e.g graphs. (See Twigger et al (in press). We were able to summarise the set of commonly occuring prior conceptions, together with the goal conceptions as specified by Newtonian dynamics, representing the conceptual reconstructions that are required for students learning dynamics.

Engel-Clough and Driver, 1986 like di Sessa (Globerson and Di Sessa, 1984) found that task context influenced the use of prior conceptions. Therefore we were very careful in our choice of contexts which are described below.

The software and curriculum

We constructed a curriculum based on four scenarios:

The 'Cardboard Box' scenario' consists of an object moving horizontally .which can be accelerated by a force applied by a human figure and decelerated by sliding friction. Two values of frictional constants were supplied related to the floor of the supermarket, and the rougher surface of the carpark. This illustrates horizontal motion with friction

The 'Rocket Skater' scenario consists of human figure, which can have two values of mass on frictionless ice can be propelled by two opposing (impulse or continuous) rockets which are mounted on the skaters back. This illustrates horizontal motion without friction.

The 'Speed Boat' scenario consists of a speedboat, moving horizontally with the application of a variable continuous force. Its speed settles down to some

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constant value, the terminal velocity. This illustrates horizontal motion with speed dependent resistance.

The 'Parachutist' scenario consists of a human figure falls vertically under gravity and against air resistance which increases with the opening of the parachute and the figure attains a terminal velocity. This illustrates vertical motion under gravity.

The children used the simulations both in structured experiments and in an informal way. The computer based experiments were designed to allow children to collect empirical data about prototypical motions, and to identify relationships between variables. The scenarios combine with support materials to form an integrated teaching package which also includes 'real' practical experiments. All of the practical work involves children in making predictions about the outcomes, providing their reasons, and then checking the outcome against their predictions. We wished to provide counter evidence to their predictions from experiences either in the 'real' or computer world. On other projects students have been observed to disbelieve the evidence of experiments or to consider it faulty data or forget it quickly and revert to previous beliefs. We believe that learners need an alternative way of conceptualising the problem before being prepared to reconsider their current ideas. The scenarios we constructed provide opportunities for pupils to construct a Newtonian set of rules for force and motion in a supported software environment, through observation of patterns of events and data on the screen. Learners also needed to assess the truth of their new conceptions by doing real experiments and discussing them. This led to the design decision to incorporate 'real' with computer practicals and the adoption of the Predict / Observe / Explain methodology (see Champage, Klopfer and Anderson, 1980) in the design of pupil worksheets.

We wished students to learning Newton's first two laws, and understand what is meant by force, mass and acceleration. To understand even simple instances of everyday mechanics we had to include : sliding friction to explain why things slow down when you stop moving them, and fluid friction (to explain why for example feathers don't fall as fast as ball bearings). Factors were added one at a time in each experimental situation to allow for easy exploration of the effect of varying them. Scenarios were linked in a sequence of activities. to deal with the prior conceptions arising when students saw some related cases as unrelated e.g.pupils intuitively treat vertical and horizontal motion as subject to unrelated rules. Further details of these type of design decisions are given in Hennessy et al, in press a.

To construct these software tools we designed a software environment called DM^3 -Direct Manipulation of Mechanical Microworlds, (Twigger et al, 1991, Draper et al, 1991) . It is an interactive simulation of mechanical motion under forces, implemented in Smalltalk -80 (as was our inspiration ARK). This environment allows the easy construction of scenarios, such as the four described above. We also implemented Varilab a qualitative modelling system through which students can express their reasoning and explanations in Smalltalk -80 and used it in some experiments reported in Hartley et al, 1991.

The classroom experiment

Our purpose in this project was to see whether we could promote conceptual change in a real school setting and make some inferences about the role that the computer played We recruited an experienced classroom teacher in a local high school who was prepared to use our curriculum and let us observe the classroom work in progress. 29 children aged 12 -13 spent seven weeks (5 hours per week classroom time with approximately 1 hour home work per week) in a mixed ability class of 13 boys and 16 girls , working in 10 small groups in triads and one pair, assigned by the teacher. As the classroom had five Mac II computers, pupils worked half time on practical work and half time on the computers. The pupils had studied their integrated science foundation course for one term. They had no other previous high school science instruction in mechanics or physics but all subjects had prior computer experience and had used a mouse. We used diagnostic tests, a pretest called "your ideas about motion", which also was given as an immediate post test and then one month later as a delayed post test. We also collected interviews with individual children, and video and tape recorded the children at work, made observer's notes, and made copies of homework and completed worksheets.

Measuring conceptual change

The diagnostic test contained a set of 15 tasks covering 12 contexts concerning horizontal motion with and without friction, and vertical motion through the air. The test was trialled with 90 children in other schools and took between 30 and 40 minutes under examination conditions. To answer each item a forced choice between alternatives was required, an indication of the degree of confidence in the answer and a justification of the answer. We looked for particular combinations of forced choices and explanations relating to each of the identified key reconstructions. Where correct predictions are made but where reasoning was ambiguous or loosely expressed, combined with a high confidence rating , some credit was given for the response.

Three independent interviewers taped private discussions with three groups which we had designated as target groups. They used a series of pictures of situations of objects in motion to prompt discussion of students reasoning in each key areas where we were trying to promote reconstructions. We wished to know the degree to which the goal conceptions were achieved and how prevalent the previously identified prior conceptions were in the class.

We found that the number of correct responses and explanations based on correct Newtonian theories increased significantly between the pre and post test and the delayed post test. We found that the pupils confidence ratings on their correct answers had also increased. However we also found that students gave more partially correct answers and were also better able to provide explanations for their incorrect responses. These last two findings are interesting as it suggests pupils are becoming more articulate about their choices but our worry that pupils might have simply become confused when the answers provided by our simulations were different to those they expected, were unfounded.

Table 1 Significant within class changes in prevalence of prior conceptions

Prior conception	Nos
Motion implies a force in the same direction	13
Exclusion of friction as a force opposing motion	5

We also found a decrease in two kinds of prior belief: fewer explanations asserting that motion implies a force were found, fewer explanations excluded the possibility that friction was a force opposing motion, and there was evidence for a greater understanding of resistive forces being directional, see Table 1. However we did find that children did expressed some new incorrect conceptions in the post test, which they had not had prior to our intervention. Two kinds of prior conceptions in particular became more prevalent over time:' forward force must be greater than a retarding force in order to maintain motion', and ' an object has force in it'.

While the pupils were engaged by the simulations and able to use them we found little evidence of a computer culture developing. We used two control groups, one from the school following a different curriculum with a different teacher (due to a last minute change in the school's arrangements), and one following a more practically based curriculum. One of our control groups did slightly better in the number of correct responses, although the pupils were one year older. However this group did not show any decline in any of its incorrect prior conceptions. Further details of the results are given in Hennessy et al, in pressb.

Conclusions

The evaluation results show that our computer based curriculum works in a real classroom to promote conceptual change. A significantly greater appreciation of Newtonian theory emerges, although some prior conceptions were in fact strengthened. We believe this was because our curriculum of experimentation and discussion helps pupils to make their beliefs explicit. We also believe that if more time were allowed for the curriculum students could complete the process of conceptual growth and emerge with secure Newtonian conceptions. The direct manipulation interface removes problems for computer novices. However we think we can say more about the process of conceptual change by looking in more detail at the trajectory of particular conceptual change episodes we have recorded.

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