Learning about motion in a multi-semiotic environment

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Students' intuitive assumptions and arguments about motion are often discontinuous with the principles and styles of reasoning underpinning the Newtonian model. Traditional approaches to the teaching of mechanics and everyday physical experience do not sufficiently challenge these assumptions and arguments. In this paper, we report and reflect on a teaching experiment conducted with college students learning about motion with MoPiX - a multi-semiotic interactive learning environment. We discuss the potentiality of new forms of representation for learning about motion.

Keywords: Mechanics; Motion; Advanced Level; Multi-semiotic: Interactive Learning Environment

Introduction

Mechanics is an area of applied mathematics in which students' informal ways of experiencing the world have often prepared them poorly for understanding scientific principles. Indeed, students' intuitive assumptions and arguments about motion, forces, acceleration, etc. are often discontinuous with the principles and styles of reasoning underpinning the Newtonian model (Eckstein and Shemesh 1989; Graham and Berry 1990). Everyday physical experience does not sufficiently challenge these assumptions and arguments. Traditional approaches to the teaching of mechanics as a part of advanced mathematics also fail to challenge them; these tend to focus on the construction of conventional static diagrams of physical systems, which are then translated into algebraic representations. The components and relationships in such systems and the principles underpinning their construction are often poorly understood, leading to errors and poor student engagement with the subject.

MoPiX, an interactive learning environment developed within the ReMath project[i], can provide students with concrete experiences that support the construction of principled understanding of motion by building and controlling animated models and investigating their behaviours. The behaviours are defined by equations, enabling students to make links between formal notations, predicted and/or observed behaviours of their models, and their developing concepts of velocity, acceleration and force. In this paper, we report and reflect on a teaching experiment with college students learning about motion with MoPiX and discuss the potentialities of this multi-semiotic environment.

MoPiX – a multi-semiotic environment

MoPiX is conceived as a constructionist toolkit (Strohecker and Slaughter 2000), providing fundamental elements (in this case objects and equations) with which students can build models and form and investigate hypotheses by activating their constructions and observing their behaviour. It has a wide range of possible applications, one of which is in Newtonian mechanics. The environment of MoPiX is essentially multi-semiotic, linking symbolic representations (equations) using a variation of standard mathematical notation, with animated models and graphs. In addition, the planned pedagogy, the social environment of the classroom and the nature of the technology (individual tablet PCs) encourage the use of a range of modes of communication, including talk, gesture, various paper-and-pencil representations and the electronic sharing of constructed objects and models through the ReMath portal [ii]. The variety of semiotic systems provides a range of meaning potentials (Kress and van Leeuwen 2001, O'Halloran 2005) and hence rich opportunities for users to construct meanings for the mathematical objects and concepts represented.

A MoPiX object is caused to move by applying a set of equations defining the way in which its position should change over time. For example, the set of equations shown in Figure 1 would cause object_1 to move in the horizontal direction with an initial velocity of 3 and constant acceleration -0.1[iii]. Horizontal and vertical components of motion are defined separately. The notation thus supports vector concepts of velocity and acceleration, while the form of the equations embodies the definitions of velocity as change in position and acceleration as change in velocity.

x(object_1,t)=x(object_1,t-1)+*Vx*(object_1,t)
Vx(object_1,0)=3
Vx(object_1,t)=*Vx*(object_1,t-1)+*Ax*(object_1,t)
Ax(object_1,t)=-0.1

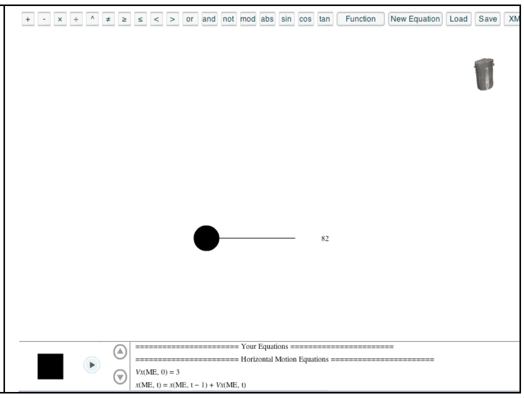

Figure 1: A set of equations defining horizontal motion

Equations may be taken from a library of basic equations, edited or authored directly and applied to objects. Once equations have been added to one or more objects, the model may be played and each object in the model will move according to its own set of equations. (It is also possible to apply equations that define interactions between two or more objects.) The visual feedback from the animated model allows students to test their hypotheses about the functioning of the equations they have used. They may then continue their investigations by editing the sets of equations and by adding new objects to their model.

The teaching experiment

A teaching experiment was conducted in a London tertiary college with a group of seven students beginning the second year of their A-level mathematics course. The students' participation was voluntary but it was seen as preparation for the mechanics module that they would study in the next term. The pedagogic plan was negotiated with the college teacher to ensure a perceived match with the examined curriculum and was taught over ten weeks by the researchers. The plan focused primarily on the development of concepts of velocity and acceleration, including: velocity as change in position, velocity and acceleration as two dimensional vectors, acceleration as change in velocity, and acceleration as a force - specifically acceleration applied at an instant. The aims of the experiment were, on the one hand, to test the hypothesis that MoPiX would support student learning of these ideas and, on the other hand, to investigate the ways in which students would make use of the various semiotic resources available to them within MoPiX and in the broader classroom environment.

Students each had an individual tablet PC but were encouraged to work in pairs. Data collected included: paper-and-pencil work (including pre- and post-questionnaires); audio records; video records of one pair during each session, capturing screen, gesture and use of other modes (e.g. paper and pencil, calculator). The video data was transcribed, capturing the multi-modal nature of the data (speech, MoPiX screen display, MoPiX equations, gesture, writing/ drawing), and coded according to strands of interest identified a priori or through interaction with the data itself (e.g. form of reference to velocity and/or acceleration; strategy for selection of equations).

We shall present two examples taken from our data analysis, illustrating the development of students' use of velocity and acceleration in interaction with the semiotic resources provided by MoPiX.

Example 1: Changing the direction of motion

In the seventh session, students were introduced to the idea of acceleration applied to an object at an instant. They experimented with applying acceleration equations of the form *Ax*(object_1,20)=3 (applying an acceleration of 3 units in the horizontal direction when time is 20), observing the effect as a sudden change in direction. They were then posed the task of using such acceleration in order to draw a square. In an earlier session students had worked on the outwardly similar task of drawing shapes (not including a square) by making changes in velocity. It was here that Ron decided to start. Rather than using acceleration, he first used velocity equations to turn the corners of his square. After some initial hesitation he created his object, assigned it a basic set of motion equations and, after a short period of trial and improvement using strategies such as changing the signs or swapping the values of *Vx* and/or *Vy*, found the necessary equations to turn the first corner of the square. He then completed the other corners of this square efficiently and accurately. Ron's initial systematic trial and improvement strategy of changing the sign or swapping the values of the new velocity worked well in this case because of the nature of the relationship between horizontal and vertical components of velocities of perpendicular motions. On completing the task, his growing confidence was apparent as he explained spontaneously to his partner how to make an object turn right-angled corners.

He then started the task of drawing a square using acceleration equations. This task was clearly seen as parallel to the one he had just completed as he kept this model of a square formed by using changes in velocity on the screen and constructed his second model next to it, running both simultaneously and comparing the results at each stage. After making a more confident start to creating the basic motion of the new object, Ron then ran into difficulties. As he tried to turn his first corner, the change sign/swap values strategy no longer worked. At first he did not appear to see how to overcome this, resorting to alternative strategies such as doubling and trying extreme large and small values of acceleration. These strategies focused only on the values of the acceleration and his exploratory attempts appear to take no account of the desired values of the velocity. After eleven minutes and fourteen trials he succeeded in finding the values of acceleration needed to turn the first corner. Having achieved this, he proceeded to turn the other corners successfully and relatively efficiently, having to make only minor corrections. When he came to the final corner, wishing to make the object stop, he encountered new difficulty as the pattern of changes of sign and values that was successful in turning corners was not useful for coming to a stop. This seemed to require him to seek a clearer understanding of how acceleration was working in his model; he flipped over the two models and examined the equations used in each case, apparently comparing the values of velocity and of acceleration at each of the corners. With significant pauses for thought, he succeeded in adding correct acceleration equations without further trials. Finally, having completed a correct model, he spent time inspecting the equations of the original model built using changes in velocity, pointing to the various values of velocity as if calculating what acceleration would be needed to achieve the same effect. Table 1 compares Ron's processes as he attempted the two tasks.

Velocity	*Acceleration*
tentative start, adding and trialling subsets of basic motion equations for first side of square	confident start: basic equation set added immediately
trial and improvement (4 trials) to achieve first turn; change sign/ swap values strategy	trial and improvement (14 trials) to achieve first turn - wide range of strategies
rapid, accurate addition of equations for subsequent turns without trialling	subsequent turns: x and y components added and trialled separately; only sign corrections needed
general statement for producing right turns	inspection of equations and extensive pause for thought

Table 1: Drawing a square using changes in velocity or acceleration

Ron's earlier experience with MoPiX enabled efficient association of change of direction of motion with change in values of horizontal and vertical components of velocity. However, his initial use of acceleration to achieve a similar effect did not appear to make use of the concept of acceleration as change in velocity. Engagement with the symbolic mode in MoPiX and interaction between this and the animation mode enabled him to complete the task successfully. His final period of inspection of the sets of equations for both objects, pointing in turn to the velocity equations used at each corner of the original model, suggests a move towards a focus on acceleration as change in velocity.

Example 2: Development in forms of description of motion

In paper-and-pencil questionnaires in the first and final sessions of the teaching experiment, students were asked to respond to the same task:

> Imagine throwing a tennis ball against a wall.
>
> Draw a picture showing how the ball moves after it leaves your hand.
>
> Describe in words how the ball moves and how its motion changes.

In Figure 2, we compare the responses of one student, Tom, before and after experience with MoPiX.[iv]

Before using MoPiX	*After using MoPiX*
	
The ball flies towards the wall losing height then it hits the wall losing some energy to the wall out as sound, bounces off the wall continues falling but in a different direction.	As it is flying towards the wall its x velocity doesn't change while the y velocity is decreasing. When the ball hits the wall, the x velocity changes direction (becomes negative) and some energy is lost to the wall, the y velocity keeps decreasing at a rate of -9.8. As the ball hits the ground y velocity changes direction.

Figure 2: Tom's pre- and post-experiment description of motion

While there are similarities in the ways Tom has described the motion of the ball (e.g. 'flying' towards the wall, loss of energy to the wall), his second description contains new features that suggest a more precise understanding of the nature of the motion as well as use of formal and quantifiable notions of velocity and acceleration due to gravity. The contrast between equivalent parts of his descriptions is shown in Table 2.

Before	*After*
losing height	its x velocity doesn't change while the y velocity is decreasing
bounces off the wall	the x velocity changes direction (becomes negative)
continues falling	the y velocity keeps decreasing at a rate of -9.8
-	As the ball hits the ground y velocity changes direction

Table 2: Description of motion before and after MoPiX

In his post-experiment description, Tom makes consistent use of a scientific register, using *velocity* as a means of describing motion rather than more everyday terms such as *losing height*, *bouncing*, *fallin*g. His separate description of horizontal and vertical components of motion provides a basis for the vector based problem solving demanded by the traditional curriculum. He also expresses the idea that velocity is constant unless a force acts upon it (hitting a wall or the ground; acceleration due to gravity).

Conclusions

Through the course of the teaching experiment, we can identify indications that experience with MoPiX supports students' acquisition of ways of operating with velocity and acceleration that are compatible with their formal definitions and with Newtonian laws of motion. In the two examples offered here, this is evident in Ron's eventual fluent construction using changes in both velocity and acceleration and in Tom's post-experiment description of the motion of a ball bouncing against a wall. More generally, our data from later sessions show extensive and consistent separation of horizontal and vertical components of motion. Of course, we would not claim that the short period of MoPiX use could overcome all problems with motion concepts. In particular, we found that acceleration was still often talked about in 'everyday' ways that were not consistent with a formal definition of the concept and did not support successful problem solving.

An important feature of MoPiX is the provision of both symbolic and animation/visual means of representing motion. The interaction between symbolic and animation modes during problem solving, as seen in example 1, allowed the focus of students' attention to shift between the motion itself and its formal definition and to make direct connections between the quantitative expressions of velocity and acceleration in the symbolic mode and the qualitative effects observable in the animation mode. The possibilities afforded by new technologies to relate symbolic and visual semiotic potentials have been exploited in other microworld environments, notably those based on Logo turtle geometry. One of the major challenges in designing such environments for use in mathematics teaching and learning is to match the characteristics of the symbolic resources sufficiently closely to those of conventional mathematical language in order to allow students to relate meanings constructed in one context (the microworld) to those relevant in the other (the mathematics classroom). In the case of MoPiX, the symbolic representations were adopted and adapted into the students' oral and written language through the course of the teaching experiment as they increasingly made use of component related terms derived from the MoPiX language (e.g. 'x velocity'). While we have not followed these students into their study of the mechanics module, we contend that at least this new element of their semiotic repertoire should directly support their engagement with the conventional curriculum.

Notes

[i] ReMath (Representing Mathematics with Digital Technologies) funded by the European Commission FP6, project no. IST4-26751.

[ii] MoPiX version 1 is available at http://remath.cti.gr; version 2.0 is under development at http://modelling4all.nsms.ox.ac.uk/

[iii] Units are non-standard and not identified explicitly in the notation.

[iv] The space available only allows us to analyse differences in the written text, though there are also differences in the diagrams.

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