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ENHANCING THE LEARNING OF MECHANICS WITH GRAPHICAL TOOLS

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1 Introduction

Mechanics presents severe difficulties to students. Recent advances in computers technology have encouraged researchers to look at how they may be used to enable students to overcome such difficulties. Our key motivation for choosing mechanics is threefold. Firstly, and most importantly, one of the authors (Sapiyan) has taught mechanics for more than ten years and has seen the difficulties students face. Secondly, it has been reported by numerous researchers that conventional instruction on its own (via lectures and tutorials), is inadequate and ineffective for students learning mechanics, hence specialised tools are required. Lastly, knowledge of mechanics is needed to serve engineers and students of the pure and applied sciences.

In this paper we restrict ourselves mainly to the problems of motion. Our goal is to produce a suite of computer tools to facilitate the learning of this difficult subject. The plan of the rest of the paper is as follows. Section 2 briefly summarises and provides some general explanations of problems faced by students when learning about motion. Section 3 presents our hypothesis, i.e., what we are doing to address this problem, and provides some cognitive justification for our hypothesis. Section

4 describes our suite of tools. In the final sections, we report on some other related works and our preliminary conclusions.

2 Students' Difficulties with Motion Problems

Mechanics is a broad subject which transcends several domains including Mathematics and Physics. Students learning the subject face many difficulties. As mentioned in the previous section, we restrict our discussion to the topic of motion. Before we discuss the difficulties, we briefly describe the topic.

2.1 Some Definitions

Motion is the act of (a body) changing position and is usually associated with distance and time. The ideas of distance and time are developed into the concepts of displacement, velocity and acceleration; their study is called *kinematics*. Kinematics can be one-dimensional (i.e. rectilinear or straight line motion), but often it is two-dimensional, e.g. in projectile and circular motion. Projectile motion is the motion of a projected body under the influence of gravity; its trajectory is a parabola. Circular motion, as its name implies, is that of a body moving in a circle.

2.2 A preliminary study

We ran a preliminary study on the learning of motion among secondary school students. Our goal for conducting the study was not to gather data for quantitative statistical analysis, rather it was more to confirm that the stated problems that students face in learning mechanics, which had been reported in many previous studies, e.g. (Sapiyan & Nusna 1994, Halloun & Hestenes 1985), are also prevalent amongst UK pupils (the principal author is comes from Malaysia). Nine 15 year old pupils of the Holden Lane High School in Stoke-on-Trent, England were given some basic questions on kinematics.

Subjects. The subjects were pupils of average and above average abilities preparing for the GCSE. They had been taught kinematics and simple dynamics in their physics course.

Method. The exercise took three sessions each lasting thirty minutes. These were pen-and-paper exercises. In the first session, the students were given some basic questions about mechanics and dynamics. The students were asked to:

- give the definitions and explanations (in their own words) of the basic concepts of kinematics: distance, displacement, speed, velocity and acceleration.
- identify concepts which are similar and explain why they are similar and where/how they differ.
- state what happens to displacement and velocity for motion with or without acceleration.
- identify what happens to a body when a force is applied to it. The body may initially be stationary or in motion. The direction of the force may (or may not) be in the same direction as that of the motion.

In the second session, they were given a basic kinematics problem after some explanation of what displacement is. In the third session, they were set the following problem: two cars are travelling on a road. One is overtaking the other. When they are level, what are the velocities of the cars relative to each other?

Results and discussion. None of the students was able to define the basic terms of kinematics. Only half of the students were able to explain what the terms mean, but the explanations did not involve the concept of vectors. None of the students understood what the term 'displacement' means. Most students seemed to think that velocity and speed are similar, but could not explain why or identify the differences. These results clearly indicate that the vector concept may have been avoided in their teaching as it is relatively difficult. This is supported by the way a recommended book (Bethell & Coppock 1994, p. 11) introduces the concept of motion:

> Acceleration tells us how fast the speed of something is changing.

The same book then defines the concept as:

$$\text{acceleration} = \frac{\textit{change in speed}}{\textit{time taken}}$$

Note that in both cases above 'speed' has been used instead of the more appropriate term 'velocity'.

The students seemed to understand the relationship between velocity and acceleration, i.e. when there is an acceleration, the velocity is increasing. Only one student was more precise, that acceleration is directly related to the change in velocity. However most students understood that force causes a change in velocity and may accelerate, slow down or even change the direction of a moving body. Nevertheless, some of the students seemed to think that the final direction of the motion is always in the direction of the most recently applied force, which agrees with most previous studies, e.g. (White 1981).

After some explanation, the students seemed to understand the concept of displacement. However, a few students still did not get the correct answer to the basic displacement problem. The problem of a car overtaking another also caused much confusion, with half of the students saying that the velocities of the cars are the same when they are level.

The students' understanding of kinematics was not very different from those without any formal instruction in mechanics. The concept of vectors, in particular, is difficult and often avoided in school mechanics. The students have many misconceptions which, unfortunately, traditional instruction has not been able to deal with effectively.

2.3 Summary of difficulties in learning motion

After reviewing a large number of studies, e.g. (Caramazza, McCloskey & Green 1981, Driver 1981, Gang 1993, Hestenes, Wells & Swackhamer 1992, Hewson 1985, McDermott, Rosenquist & van Zee 1987, Mestre & Touger 1989, Reif 1985, Trowbridge & McDermott 1981, Warren 1979, White 1981) and from our preliminary study and experience, we restate the pupils' difficulties with motion as follows:

- Vocabulary: students do not understand and unfamiliar with the fundamental concepts, e.g. vector quantities are treated in a similar manner to scalar quantities.

- Concepts are confused and different concepts are used wrongly and interchangeably. The relationships between concepts are often misunderstood.
- Students' technique for problem solving in the study of mechanics degenerates to applying formulae and rote learning (mechanics teaching rarely confronts this issue).
- Hence, students often possess no qualitative understanding of mechanics and little meta-cognitive skills, especially self checking and self questioning skills, e.g., does this answer make sense?

2.4 A brief explanation for the difficulties

Traditional instruction and assessment of mechanics are partly to be blamed for these problems. Lectures are merely the presentation of the content of topics to be learned. Tutorials, though meant to help conceptual understanding, tend to be exercises in algebraic manipulation. Thus, although students are able to obtain correct answers, it is rarely the case that they understand the concepts involved. On the other hand, even when they get an incorrect answer, they do not realise that they have misconceptions in their knowledge. Even if the problem is pointed out to them, they do not have an effective method or the tools to deal with it. Instruction is usually geared towards learning quantitative knowledge; the same is true of assessment. The relationships between entities are thus expressed in formulae, from which answers may be calculated, without the students necessarily understanding what they really represent. In summary, traditional instruction and assessment encourage rote learning rather than conceptual learning.

In addition, the nature of the subject is itself problematic. Students' daily experience often contradicts the scientific theory. For example, Newton's laws of motion do not match with their real world experience due to the existence of factors such as friction.

3 Hypothesis and Justification

Considering the students' difficulties in learning mechanics, discussed in the previous section, we postulate an hypothesis about instruction in mechanics, in an attempt to facilitate its learning. We also provide cognitive justification in terms of the guiding principles of our suite of tools.

3.1 Hypothesis

Our primary belief is that carefully designed computer software tools can help students to be more aware of their learning and minimise many of the problems students face in mechanics. However, we believe that the most effective approach is not in developing tools which *directly* teach mechanics; rather we seek to provide tools which students can use to explore the domain, which confront their misconceptions and confirm or refute their beliefs. The tools will encourage the development of their meta-cognitive reflection skills. In brief, we propose a set of meta-learning tools for mechanics which will not necessarily "teach" the students as intelligent tutoring systems (ITSs) strive to do. Rather *they will facilitate the acquisition of meta-cognitive knowledge schemas which will, in turn, allow for the generation of that knowledge required to solve typical introductory mechanics problems.* We expect that, with this sort of knowledge, students will be able to realise *when*, *where*, *what*, *why* and *how* to apply different knowledge types in mechanics.

We also believe that student collaboration is a powerful tool in learning, which should be exploited. However, for collaboration to occur, students working in a group need proper tools to represent their ideas and understanding, to help them communicate effectively. Tools with sufficiently rich representations are therefore necessary for meaningful collaborative learning.

3.2 Justification of Hypothesis

Our meta-learning hypothesis for mechanics is justifiable on many grounds, which may be considered as guiding principles for the development of our suite of tools. They are to:

1. *Encourage conceptual understanding, not rote learning*

   Conceptual learning requires learners to understand each individual concept of a subject. A proper understanding of the concepts is not possible without studying their attributes and relationships with other concepts. To understand a domain such as motion implies that learners need to understand the role of concepts in the description of various events involved in motion

When considering an event such as an object *free falling*, the learner needs to know what concepts are needed to describe the event. They also need to distinguish which concept describes an event better than another, or when a concept can only describe certain aspects of the event and requires other concepts for a more complete description. This deeper understanding helps learners to realise which concepts need to be considered in a given problem situation for problem solving. On the other hand, rote learning does not encourage any of these. When someone learns something by rote, the consequence is that very few sensible connections are established. We then say that they do not really understand. As Minsky explains:

> Rich-meaning networks, however, give you many different ways to go: if you can't solve a problem one way, you can try another (Minsky 1985, p. 64).

It is our goal to imbue students of mechanics with such 'rich-meaning networks'.

2. *Negotiate, not teach*

Traditional instruction attempts to transfer the 'correct' knowledge to students. With mechanics, this is just plain wrong. This is because motion is a most ubiquitous phenomenon which everyone experiences and learns before being formally taught. Hence, before formal tuition, they already possess some correct, inaccurate, incomplete, or plainly wrong models of the subject, including its terminology and vocabulary (e.g. velocity, acceleration). These models have served them well for many years, and so it is unrealistic to expect direct instruction to achieve an immediate abandonment of these deeply-held schemas. We argue for a *negotiation* (Moyse & Elsom-Cook 1992a) process which will facilitate the gradual restructuring of their schemas to *accommodate* the 'correct' knowledge (Ginsburg & Opper 1969).

3. *Situate the learning experience*

With special software tools, we can attempt to replicate or recreate real world events, and also to extend and to manipulate aspects of physics for teaching purposes. In order to get students to acquire the necessary meta-knowledge (i.e. 'when', 'where', 'why', 'what' and 'how'-type knowledge), tools are required to provide the environment for their acquisition – it cannot be acquired by rote

Interacting in the environment provides experiences that show *when and where certain concepts are needed*. Without the realisation of the unique role of each concept in the description of the domain, learners will find it difficult to apply the correct concepts in describing different events or situations. This "knowledge is not independent, but rather fundamentally 'situated' being in part a product of the activity, context and culture in which it is developed" (Brown, Collins & Duguid 1989).

4. *Learn concepts via the 'enactive-iconic-symbolic' cycle*:

   Since studies have clearly demonstrated that children totally decouple equations (i.e. the symbolic) from their physical events, we propose an environment which will implicitly couple the symbolic equations to the different types of motion. In this regard we have been influenced by Bruner's work on how children learn arithmetic (Bruner 1966). Bruner's theory notes that knowledge can be represented in three forms:

   - Enactive - i.e. concrete actions or objects, e.g. an abacus, toys, movement, etc.
   - Iconic - semi-concrete actions or objects, e.g. visual perception, pictures, images, etc.
   - Symbolic - more formalised knowledge, e.g. $x = 2$.

He sees knowledge as being acquired via a spiral curriculum of enactive, iconic and symbolic processes. We argue that problem solving requires accurate symbolic representation of problem situations, which implies that the students need to have accurate visual images (*iconic*) and the 'right' experiences (*enactive*). Hence, a student should be made to be aware of their learning difficulties with reference to the different levels of learning, i.e. being more critical of their own thinking. This is very much in line with an objective of formal education, which is to refine and sharpen the power of thought, in whatever discipline it may be:

> Education is about acquiring the ability to collect, manipulate and apply information for the purpose of understanding and therefore mastering a given subject matter; it must, therefore, be about thinking and thinking to some purpose (Mudune & Davis 1991, p. [illegible]).

5. *Enhance the acquisition of qualitative knowledge.*

Qualitative knowledge is usually required to solve problems. For some problems, qualitative knowledge is absolutely essential. Without it, it would be impossible to solve the problem (Plotzner 1994). Both novices and experts employ qualitative reasoning when they consider a physical domain. Experts, however, reason qualitatively about a phenomena before they resort to quantitative formalisation (Chi, Feltovich & Glaser 1981), whereas novices are only capable of qualitative reasoning, which is often incorrect, without linking it to any quantitative knowledge. On the other hand novices, with some instruction in mechanics, leave aside the qualitative knowledge, and concentrate on the quantitative knowledge to reason out the phenomena (White & Frederiksen 1990). We believe that meaningful learning cannot be achieved unless students are encouraged to continue to reason qualitatively in conjunction with the new knowledge, which is often very quantitative.

6. *Reify better mental models via progressive model evolution.*

Learners mental models of physical phenomena need to be evolved from naive ones towards those of the expert. This can be achieved when a learner interacts with models of physical systems whose complexity increases progressively as the learner assimilates each model (White 1993). For certain domains, e.g. motion, there is a need for some students to be persuaded to accommodate [in the sense used by Piaget (Ginsburg & Opper 1969)] the expert's simple models of the systems, which contradict the learner's intuitive but deeply-held mental models. These models should embody alternative but coordinated conceptualisations of the system's operation, in terms of its functionality or structures, for example. We believe that by assimilating these models, students' mental models will become sufficiently rich and accurate to enable them to solve problems.

7. *Encourage "holistic" learning of concepts.*

Motion is normally taught in a static context. However, because motion is dynamic, various concepts involved never really "gestalt" in the students' minds. The whole of the dynamic phenomena is always greater than the sum of the *individual static parts*. Holistic approaches enable learners to understand organised wholes due to the integration of parts by recognising and using organising principles. Atomistic approaches lead learners towards making sequential rather than hierarchical links between parts of the subject. Without looking at the structure as a whole in relation to a task, the learner will not appreciate the meaning of answers they come up with when solving problems (Laurillard 1993). Hence, a key goal is to provide an environment which allows for such *holistic* learning to occur.

4 Tools for learning motion

In this section, we describe some of the tools we have implemented on a PC, using Toolbook 5.0 developed by Asymetrix, as the authoring tool. For the conceptual learning (principle 1), we have integrated 3 separate tools: simulation, microworld and concept map tools. These tools are designed to be used both by the students as well as teachers in a course about simple motion.

With any learning environment, a method of delivering information to the students is necessary. We present this in the form of hypertext, which includes dynamic graphics of simple straight line motion and some tables for students to enter their answers to some basic questions. These are shown in Figure 1. Here the students are introduced to simple concepts of kinematics, such as position, distance and displacement. In Figure 1, the car started at position 2, moved to position 4 and back all the way to -4 and then stopped at position 0. Hence the distance covered is 14 while the displacement is -2.

To test their understanding of these simple concepts, the students are then asked to do some simple tasks. An example of such a task is to find how an object can be moved from a certain initial point determined by the student, so that the distance and displacement of the object at a particular point satisfy some given values. The students can try it out and the simulation visually demonstrates that they got it right or wrong. If they get it wrong, they have to work out why. They can again employ the simulation by playing it at a slower rate or stopping the motion at certain points to investigate how the different values vary.

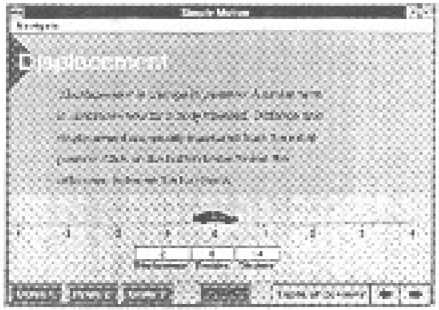

Figure 1: A screen dump of the presentation of concepts

4.1 The Simulation Tool

The simulation tool (see Figure 2) consists of graphics showing

- some simulated motions, e.g. cars slowing down to a halt, rockets circling around the earth at constant speed, etc. Blobs are used to represent a generic object.
- scales and a clock face to show the displacement, velocity, acceleration, change in displacement and/or change in velocity, as the motion progresses. The scales and clock face are made analogue to encourage qualitative rather than quantitative reasoning. For two dimensional motion the scales are modified to display both the vertical and horizontal component of the concepts.

Students can display different types of motion using the simulation. This is done by specifying values for the parameters which determine the type of motion. For example, a uniform linear motion may be identified by providing a value for its initial velocity and zero for its acceleration. In addition to being able to repeat the same motion as often as is required, the student can also stop the motion at any time to give them the opportunity to reflect on the concepts, before continuing with the motion again.

The simulation is initially restricted to rectilinear motion with (or without) constant acceleration. However, an option for a two-dimensional motion may be chosen from the menu. The two-dimensional

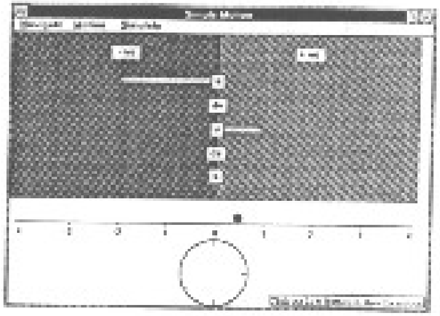

Figure 2: A screen dump of the Simulation tool

motions provided include those with constant as well as variable acceleration. Hence, projectile, circular and simple harmonic motions are covered. The tool can also simulate the motions of two bodies, which will be very useful to refine students' understanding of the domain.

This tool can be used to experiment with particular ideas that the student has. The student can make a guess as to the outcome of certain values being given to the parameter, and then observe if his guess is correct. It is also used in combination with the concept map tool (see Section 4.3). The simulation tool can utilise some of the information obtained by the concept map tool to provide more information on certain concepts such as velocity or acceleration, for the student to reflect on further. This can be in the form of a graphical comparison of the concepts, at every instant of the motion.

In summary, the simulation tool facilitates the learning of defined concepts such as displacement, velocity and acceleration. It is also useful in helping students appreciate the subtle differences between closely related concepts, e.g. distance, displacement and position; and speed and velocity.

4.2 The Microworld Tool

The microworld tool is an extension of the simulation tool. The main difference between the two is that with the microworld learners have more freedom in determining the type of motion displayed. While the motions produced by the simulation are predetermined by the values of the parameters entered by users, motion in a microworld can be controlled by users by depressing certain buttons provided by the tool (see Figure 3). Virtually all one-dimensional and two-dimensional motions are possible with the tool, once the students have mastered how to control the motion with the buttons. However, unlike arcade games, the students need to express what they understand from their experience using the concept map tool (see Section 4.3). *The microworld is designed for users to experience the causal relationships between concepts in motion.*

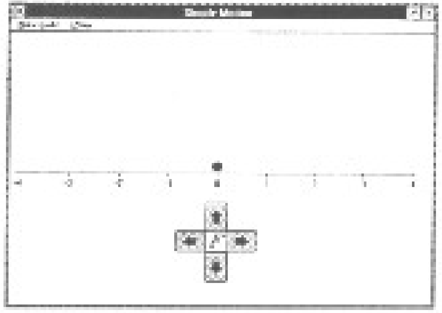

Figure 3: A screen dump of the Microworld tool

The task that students are asked to do using the microworld is to produce the motion that they have seen displayed using the simulation tool. The tool provides an instant feedback to their hypotheses about causal relationships involved in motion. They can then use the feedback, and repeat the exercise and try to improve on the previous attempt if they have not been successful. This experimentation is carried out with reference to what is being 'taught'. Hence, they are encouraged to link what is being 'taught' via this environment to their experience. The knowledge acquired is thus 'situated' [Principle 3]. So students are not forced to accept the 'correct' knowledge, rather they are encouraged to discover, albeit with some guidance, the 'more accurate' alternative conception of the domain. Thus, the interaction with the microworld confronts the students' misconceptions and helps to *potentially* remove some of these misconceptions (Principle 2).

4.3 The Concept Map

This tool uses ellipses to represent basic entities of the domain, arrowed lines for links between concepts and rectangles for attributes of the entities which describe the motion (see Figure 4).

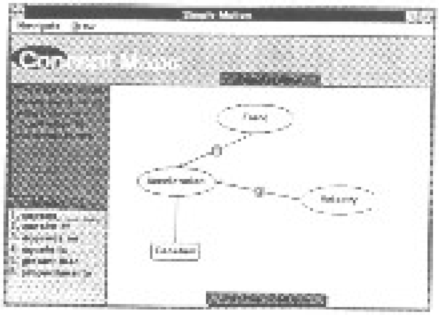

Figure 4: A screen dump of the Concept Map tool

At the bottom left-hand corner of Figure 4 is a list (shaded). Above it is some instruction for the user. The contents of the list depend on the type of list chosen from the menu *Draw*. It could be one of four lists: different types of motion; entities or elements of motion; pre-defined links; and attributes. To use the concept map tool, the student first describes the motion by clicking on the type of motion from the list. They are then required to identify the entities involved in the motion effectively to describe the motion by identifying the concepts involved and creating a visual depiction (concept map) of that motion. As each salient entity is clicked, it appears as a named ellipse on the white area of the window. These objects can then be rearranged, if required, by dragging them to appropriate positions. From the *Link* list, the student can then choose the type of link to show the relationship between one entity and another. This is done by clicking on the item on the list and then right-clicking the two corresponding objects. The link is drawn showing the link from the first object to the second object. The student then has to specify any attributes of the entities displayed. This is done in a similar manner, by clicking on an item of the appropriate list and then right-clicking the attribute object and the concept object to link them. If the student needs to make changes they can easily delete objects that have been drawn by double-clicking on the objects, and replacing them with something else. This tool is used in conjunction with the other two tools. *Its objective is to capture what the student understands from their observations of the motions shown in the simulation tool. Thus, with this tool students can express their understanding in a concrete way.* The concept map drawn in Figure 4 is an example of what could be drawn using the tool to describe an accelerated motion observed from a simulation of its motion.

4.4 The integration of the three tools

The three tools that we described in the previous subsections are used to enhance the learning of the concepts of motion. We have taken account of the cognitive principles outlined in Section 3.2 in developing our learning environment and integrating the tools. The objective is to help students acquire sufficient conceptual understanding before they proceed to problem solving.

In developing the learning environment, we began with the premise that adequate learning needs a close horizon for the students to work within, to concentrate their attention on a restricted conceptual domain. We thus start with the simplest form of motion, and gradually introduce more concepts involved in the motion, only in so far as to make it possible to link the domain with what they are familiar with from their real world experience, but not to complicate the subject too much. This helps the students to build upon or reify their mental models of the domain.

The environment starts with the presentation of the concepts using some text and simulations. This initial stage obviously involves some rote learning. However, the simulation gives the students the opportunity to assimilate the information, if it is compatible with their knowledge structure. Otherwise, their misconceptions will be brought to their attention when they use the tools to perform some investigative exercises.

The students are then asked to observe a motion chosen from a library of different types of motion categorised according to their complexity. They then try to summarise what they observe by identifying the concepts involved, how the concepts relate to each other, and what attributes of the concepts, if any, determine the type of motion shown. This information is captured by the system and displayed to the students when they confirm the completion of the exercise. The students are then required to observe again the simulation of the same motion to confirm if they have understood the concepts involved in that particular motion. This latter display of the simulation also includes extra information about the concepts that the students think are involved. This information is shown by the scalar bar or the clock hand (see Figure 2). The students are also required to validate their ideas with the microworld tool. Moving from one tool to another is via the menu *Navigate* which gives the different types of tools available.

Within the microworld, the students are required to produce the same motion using the causal relationships that they understand. Hence, if their understanding is not accurate, they will not be able to produce the same motion. They then have to review their hypothesis about the causal relationship. Experimenting with the microworld will give the students sufficient opportunity to explore within the scope of the target domain, to realise deep rooted misconceptions and to be persuaded to accept the 'correct' models. Unlike the more prescriptive approaches of computer-tutoring, the environment does not attempt to anticipate all possible mental states of the learner. Instead it provides a flexible manipulation environment which is as versatile as possible within the scope of the target domain.

What do we expect to achieve with this suite of tools? Among other benefits, we believe that:

- the environment with the integrated tools encourages a learning-by-doing paradigm for the conceptual learning of the targeted domain (Principle 1). This is achieved by making the students identify the salient concepts for different motions and their relationships with other concepts. As a result, rote learning is also discouraged. It captures Bruner's enactive-iconic level via the simulation and the microworld, and proceeds to the initial stage of formalising the concepts towards the symbolic level via the concept map (Principle 4). The learning is also very qualitative in nature (Principle 3) and provides a better overview of what happens when motion occurs via the cyclic and iterative use of the different tools. Hence, the learning is more holistic (Principle 7);

- the simulation and microworld are able to highlight obscure events or aspects of a motion not usually captured by traditional instruction. These tools also do not diagnose and correct the students' mistakes. Rather they allow the students to discover them for themselves in a more natural environment not too detached from their real world experience. Hence the knowledge is negotiated (Principle 2) rather than forced onto the students and is acquired in a more situated environment (Principle 3). The students are also made to work with a progression of models of the domain from the simplest form which involves the minimum of complexities to more complex models. The students can therefore better reify their mental model of the domain (Principle 4).

5 Preliminary Evaluation

We have conducted a preliminary evaluation of the tools, but it is too early to report any results for this paper. However, the experience of two secondary school pupils indicate that the simulation tool is easy to use and useful in introducing some of the basic concepts of kinematics. However, they find the concept map tool and the microworld tool more difficult to use. This is not surprising, since to use the concept map the student has to abstract the essential concepts describing the motion and filter out the less related concepts. This is the first step in the formalisation process, which is very difficult for most students, in any domain. Similarly, when using the microworld, unless the student understands the causal relationship well, it is not likely that they will be able to produce the required motion. The student also needs to get used to the control provided in the microworld before being able to use it effectively.

6 Other related works

Many researchers have studied problems in learning mechanics. (White 1993) for example, developed tools in the form of microworlds to teach electrical circuits and Newtonian mechanics. She argued for learning via progressions of increasingly complex causal models that are presented initially at an intermediate level of abstraction. We agree that this strategy is suitable when dealing with problems involving causal relationships. However, some modification is needed to deal with other, arguably more abstract relationships, such as the 'functional' relationships of kinematics. The work of Murray, Schultz, Brown & Clement (1990) uses analogies to remedy misconceptions in physics. This strategy has been successful in dealing with particular problems. It could be incorporated in a learning environment to deal with special cases which are very difficult to deal with using other strategies. However it is not always possible to come up with suitable bridging analogies to convince students to alter their understanding to an alternative view. For the domain of simple motion for example, this strategy is very difficult to implement. Many others have argued for the phenomenographic approach towards learning mechanics concepts (Marton 1981, diSessa 1983). This approach emphasises the need to approach learning from the learners' point of view by trying to understand the learners' prior knowledge, and building from there (e.g. (Laurillard 1993)). This approach is similar to that of conceptual change (Hewson 1981) and knowledge negotiation (Moyse & Elsom-Cook 1992b). The above studies and others (e.g. (Ploetzner 1993)) also emphasise the importance of qualitative knowledge for problem solving. Our approach has also given much importance to the learning of qualitative knowledge before going on to symbol manipulation in problem solving.

Many of the researches in this area have implicitly taken the view that they are more interested in contributing to the development of a learning theory. Indeed, Ohlsson wrote that the goal of artificial intelligence and education is not to build successful instructional systems, but to contribute to the development of a learning theory with clear and specific prescriptive consequences (Ohlsson 1991). However, we wish to proceed beyond this, i.e. to provide a suite of simple but useful tools for classroom learning which will improve introductory mechanics teaching.

7 Summary and conclusion

This paper has identified a set of cognitive principles, which have driven the development of a learning environment to facilitate conceptual learning in introductory mechanics. The environment provides a smooth progression of learning stages, from the intuitive level to the abstract level required for problem solving.

In this research we have integrated many well-established theories of learning, to come up with a more general approach towards learning mechanics, through the chosen topic of motion. We believe that our approach will help students learn new concepts, remedy deep-rooted misconceptions, and acquire the skill and technique of modelling physical events, as scientists regularly do. Consequently, students will be able to appreciate how knowledge gained from real world experience may be developed, refined, reorganised and formalised, so as to be in a more useful form. This is in accordance with the situated cognitive scientists' view of knowledge as a tool [Brown et al. 1989]. Thus learning mechanics becomes a more meaningful exercise to the learners.

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