RESEARCH REPORT ON THE CLASSROOM IMPLEMENTATION OF THE SOCRATIC METHOD IN MECHANICS

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Following twenty years of international research into student 'misconceptions' offorce and motion, there is an ongoing debate about how to improve student understanding in mechanics. Following recent research into the Socratic method for overcoming misconceptions in mechanics, this research is now continuing in the classroom to evaluate the effectiveness of, and to refine, the method. At this stage of the research, the Socratic method is being developed with a view to creating a strategy for handling intuitive responses to concept questions. After an initial classroom session and a series of individual interviews with a particular series of Socratic questions, the responses were considered and the questions refined before further taped interviews. In this session we will report on initial work carried out within the topic of projectile motion. We will then discuss some of the issues raised in attempting to develop this approach.

1. Introduction

There has been over two decades of research into student intuitive ideas of force and motion ('misconceptions', 'preconceptions', 'alternative conceptions' etc.), with much discrepant data and diversity within the hundreds of papers published (Rowlands *et alI999).* What seems to be apparent is that student intuitive ideas (or *schemata)* of force and motion aren't simply formed over years of experience of the physical world, nor are they simply formed as a result of the everyday use of 'force' as a *metaphor,* e.g. 'the force of my argument', (Rowlands *et al* 1999). Rather, these ideas are formed as a response to qualitative questions *(concept-questions,* Berry and Graham 1991) asked by the teacher or researcher on force and motion, e.g. 'Ignoring air resistance, what force is acting on a thrown ball?'. In other words, student intuitive ideas of force and motion cannot be understood outside the context of the questions that prompt these ideas. The concept-question in mechanics is a diagnostic tool because it evokes and reveals an intuitive response to a question that is structured according to the Newtonian system, and is also a tool of remediation because it serves as a 'prop' or 'hint' in understanding the way the Newtonian system explains the world. The Socratic method of strategic questioning in mechanics is the asking of a concept-question and a series of related *parallel-questions,* given in response to the student's answer to the previous question but essentially having the same answer as the previous question (see the last two BSRLM proceedings: Rowlands *et al1997,* Rowlands *et al* 1998). The Socratic method in mechanics challenges the students to be consistent in their reasoning, and the much reported intransigence of student intuitive ideas may be due to the cognitive strain in forming these ideas as the students try to make sense of the questions asked.

Although there has been much reference to the effectiveness of the Socratic method in mechanics (e.g. Arons 1990, Hake 1987, Hestenes 1992, Howard 1987, Minstrell 1982), no detailed explanation or advice on its implementation has been forthcoming. For example: Is it possible to ask a series of parallel-questions that would lead to the formation of the target-concept rather than the method merely giving the target-concept a 'conceptual airing' prior to the correct answer being given by the teacher? What aspects of classroom management would be specific to the implementation of the method? When and how should the teacher involve the class in pursuing the answers given by a member of the class? Can the method be employed in a one-to-one clinical interview to reveal any laws of student reasoning in mechanics, and can these law throw light on the way the Socratic method can be implemented in the classroom? What assumptions have to be made in understanding concept-questions and are these assumptions linked to cognitive-strain, i.e. is it the *semiotic uptake* of a concept question that makes 'misconceptions' resilient to change? Kathy Green, Maxine Marcer and Peter McWilliam are experienced full-time secondary mathematics teachers who are also part-time MPhil/PhD students researching the implementation of the Socratic method in the mechanics modules of A-level mathematics. Maxine is researching the implementation of the method within the classroom context, Peter is utili sing the method in the oneto-one clinical interview context so as to examine what prompts *critical moments* in student cognition, and Kathy is examining the semiotic uptake of the language-games of strategic questioning. A brief summary of the research is given below.

2. Maxine Marcer: Research in the Whole-Class use of the Socratic Method

Following the recent research into the Socratic method of strategic questioning in mechanics, the research now needs to be taken a step further, into the classroom, in order to discover whether it is in fact possible to develop the method as a teaching strategy and, if so, its effectiveness in handling intuitive responses to concept-questions. The first step was to use a pair of concept-questions based on projectile motion with a group of Year 12 students who had just started the first mechanics module in their A-level course. Consideration was given to the types of responses that might be expected and possible parallel questions that could be used to challenge any 'misconceptions' (or rather *intuitive schemata,* see Rowlands *et al* 1999) which might come to light. The first question and resulting responses/strategies (i.e. parallel questions) can be seen in the following table:

Concept Question

Would a car leaving a cliff at 80 mph and a stone dropped from the cliff at the same moment hit the ground at the same time (ignore air resistance)?

	Response	Strategy
1.	• Horizontal velocity makes car's path longer so it will take longer to fall.	• Is there a resultant force acting?
2.	• Yes, because car is moving forward.	• Consider motion in one dimension. Was there any resultant force acting horizontally on car as it approached the edge of the cliff?
3.	• No, if speed is constant.	• So what is the resultant force horizontally after it has left the cliff?
4.	• There isn't one (*critical moment*) *but* the path of the car isn't straight so it comes down more slowly.	• Are both objects falling?
5.	• Yes	• Are they falling at the same rate?
6.	• No response	• What resultant forces are acting downwards?
7.	• Gravity	• Is this the same for both the car and the stone?
8.	• Yes	• So which object is travelling 'faster' vertically at any moment in its path?
9.	• They must be travelling at the same speed. (Critical moment)	• So would they hit the ground at the same time?
10.	• Yes, but the car will land in front of the stone.	

It was quite surprising that at R/S 1 there was no student that responded that the car would land first because it was heavier. Although I had done some preparatory work on dropping two different masses from the same height and at the same time etc., I had thought that one or more of the group may still believe deep down that the large mass would land first. However, the question about whether they have simply learned the 'correct' response remains. R/S 2 and 3 indicated that there was still some confusion about resultant force and the direction of motion. As we had just completed work on components of vectors, I decided to try and approach the problem in this way separating horizontal and vertical components. There was definitely a critical moment (with the corresponding facial expressions of cognitive conflict) for at least one student at R/S 4 and again at R/S 9 for most of them. However, some students (mainly the girls) were reluctant to become involved. A rather vehement argument between a very able student and another rather dominant member of the group (both boys) seemed to make them realise that they were confused and instead of wanting to clarify their understanding they were giving up.

The approach used with the second concept question *(Would a car leaving a cliff at 80 mph and a car travelling at a constant 80 mph from the bottom of the cliff arrive at the same point at the same time?)* caused some problems in terms of developing the Socratic method. Appropriate parallel questions were not forthcoming in my handling of student responses and so an algebraic approach was resorted to. The introduction of algebra provides no opportunities to elicit intuitive responses from students and to challenge their intuitive schemata - the Socratic method breaks down. However, if you cannot think of a parallel question then the use of algebra may be necessary.

This first attempt at implementing the Socratic method raised some important issues. It became clear, very quickly, that the process of strategic questioning is not just about being able to think (quickly) of appropriate or parallel questions when attempting to challenge students' intuitive schemata. It is also about managing the students in that situation. Various problem arose and need to be addressed:

- How to cope with students who dominate the discussion. This is particularly important if he/she apparently knows all the 'right' answers. In this situation other students have a tendency to just sit back and agree.
- How to check that concepts really have been understood by asking further parallel questions which appear very different from the original - this is important in ensuring that correct responses have not simply been learned.
- How to ensure that *all* students are challenged and contribute to the discussion without fear or embarrassment.

3. Peter McWilliam: Research into the one-to-one use of the Socratic Method

Following the initial classroom trial with the two concept questions above, it became clear that it would be useful to know exactly when the questions were being effective. Given the problems of obtaining this information in a classroom situation, it was decided that one-to-one interviews would be a more useful tool to identify *critical moments.* These are moments of realisation where a student discovers that his existing schemata can no longer support the scenario under discussion. The following (abbreviated) transcripts show two different students tackling the two concept questions. Of importance is:

• whether or not the question caused cognitive conflict, leading to critical moments,

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b

- when exactly did the critical moment occur, and
- correlation between critical moments.

In all interviews Question 1 refers to the problem involving a car leaving a cliff at 80 mph (horizontally) and a stone dropped at the same time. Question 2 refers to the parallel questions, if a car leaves a cliff at 80 mph (horizontally), as another car comes out of a tunnel at the base of the cliff, where does the first car land in relation to the second?

Interview 1. : Tom (R: Response, Q: Question)
Question 1: R: Both car and stone hit the ground at the same time. All due to gravity same for all objects. (Very confident of this!)
Question 2: R: The car from above lands behind the one on the ground.
Q: Does the car from above have further to travel, and if so in what sense?
R: No, but weight slows it down (no as in, no further horizontally).
Q: Which direction does weight act?
CRITICAL! R: Down, so this doesn't affect the horizontal motion. Ah, it lands on top.
Interview 2: Matt
Question 1: R: Hit the ground at the same time.
Question 2: R: Top car lands behind.
Q: As you emerge from the tunnel you look up. What do you see?
R: The whole car at the start, but then you see less of it.
Q: So you suggest the top car is slowing?
R: Yes
Q: What is slowing the car?
CRITICAL! R: Nothing. Not gravity anyway, so its not slowing. It must land on top.

These interviews were conducted with the student having no prior knowledge of what was to be asked. Conclusions are not being drawn at this stage. The purpose of the exercise was to enlighten others to the nature of the research, and to help decide how best to analyse the effectiveness of the Socratic method as a pedagogy.

4. Kathy Green: The student's use of Language in Considering Concept-Questions

Taped in-class discussions of the two projectile questions provided the material for a more in-depth consideration of student/teacher use of language. As with Peter's students, my Year 12's and Year 13's intuitively answered the first question correctly, consequently I did not follow through with a parallel question in the hope of creating cognitive conflict as there did not seem to be any grounds for conflict. However, the students were eager to continue a discussion on the motion of these different masses. I interpreted this as their desire to bring precision into their use of such terms as the 'force of gravity being constant/being the same', 'falling' /accelerating', 'weight' /'mass' so that

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they would more clearly establish a relationship between the mass of an object and the force of gravity acting on that object. Prompting and prolonging the discussion and asking students to give reasons for their answers, the use of certain words betrayed a less than full confidence in their meaning. The uncertainties in both groups can be linked to two related concepts. We were in effect discussing these underlying questions: a) Why would different masses if simply dropped hit the ground at the same time? b) Can we say that gravity affects different masses in the same way? The transcripts showed the different means by which each group used language in identifying these two underlying questions and in responding to the Socratic method.

As student use of language became more precise the opportunity for parallel questions was good. These parallel questions provided opportunity for confirmation of ideas or additional attempts for those still forming their own understanding.

In our research using concept-questions in a Socratic dialogue with our students, we have a great cognitive territory to explore. The manner in which we and our students use language to direct attention, progress thought, and create precision in the application of concepts should supply a wealth of observations. From these observations we hope to form a practice of strategic questioning aiming at students giving thorough and precise answers in preference to merely the right answers. **References**

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