MISCONCEPTIONS OF FORCE: SPONTANEOUS REASONING OR WELL-FORMED IDEAS PRIOR TO INSTRUCTION?

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Throughout its twenty five year history, the conceptual change literature assumed student misconceptions of force are formed prior to instruction. We argue that it may well be the case that misconceptions are not formed until the student considers force and motion in a scientific context for the first time. This has obvious implications for research methods. We are in the early stages of developing a research method for investigating conceptual change in mechanics. To illustrate this method, we have taken examples from one-to-one Socratic tutoring to show how the characteristics of misconceptions can be explained with respect to strategic questioning.

INTRODUCTION

Research into conceptual change is vast. It is the leading area of research in science education and its domain has extended to other school subjects, such as mathematics, geography and religious education. It began primarily in the 1970's with research into student 'misconceptions' of scientific concepts with force and motion in particular. The recognition that students have 'intuitive beliefs' of force and a corresponding sense of which they can either change/modify/evaporate might well have began with the Mathematical Association's *A Second Report on the Teaching of Mechanics in Schools*:

> Pupils are inclined to think that force would be needed to keep a body moving even if resistances could be eliminated – i.e. that force is responsible for speed and not for acceleration – and considerable discussion might be required to eradicate this belief. (M.A. 1965, p.25)

'Misconceptions' are cross-cultural, span the age range and can appear independently of cognitive development. What is perhaps a little disconcerting is that they can also appear independently of instruction. For example, many physics graduates have misconceptions of force and motion (Jagger 1985; Peters 1982) and many pupils in general hold a 'dual perspective' in which they can algebraically frame a quantitative problem involving thrown balls, yet include the non-existent 'impetus' force to a thrown ball (Gilbert et al. 1982; Perkins and Simmons, 1988; Berry and Graham 1991). However, what is a 'misconception'/'preconception'/ 'intuitive belief'/ 'alternative framework' or 'alternative concept' of force? [1]. A related but bigger question is 'what changes when conceptual change occurs in the mind of the child/student/layperson/expert?' Only now have researchers attempted to answer these questions (Caravita, 2001).

Since the very influential articles by Driver and Easley (1978) and Posner et al. (1982), the conceptual change literature assumed that ‘alternative concepts’ (or whatever) are either formed phenomenologically in making sense of the physical environment or formed socio-culturally in the use of scientific terms as everyday metaphors. The problem is that we cannot ‘get inside’ the mind of the student, so the nature of ‘misconceptions’ of force or where they come from is not obvious. The big assumption is that these concepts are formed prior to instruction, but as yet there are no satisfactory theories as to how they are formed. It might be more fruitful, however, to assume the converse: that these misconceptions are spontaneous in the sense that they are formed for the first time in considering force in a scientific context for the first time. The implication is that the object of research ought to uncover elements of pre-formed ideas in student reasoning rather than merely assume them.

The problem is one of method. It may well be the case that any research instrument cannot ‘capture’ a misconception that was pre-formed, but was instrumental in its formation. Many existing taxonomies of misconceptions may be more a reflection of what kind of misconception is prompted by asking what kind of question *for the first time* [2], than what is in the student’s ‘head’. Despite any attempt to remove bias, a question or a series of questions in a clinical interview might be instrumental in instigating misconceptions and promoting conceptual change (or, conversely, creating confusion). Despite any removal of bias, asking a question that presupposes a Newtonian answer is to ask a question that demands a sophisticated form of reasoning in Newtonian mechanics. That demand is a cognitive one and does not ‘capture’ how the student ‘sees’ the world through her intuitive beliefs about the world. In other words, any research instrument may be a form of intervention in which conceptual change is a response to that intervention.

The Centre for Teaching Mathematics is developing a method of research that views misconceptions as dynamic responses to questions that demand Newtonian forms of reasoning. The method involves Socratic questioning which may instigate a misconception for the first time but attempts to direct the student to a Newtonian understanding of force and motion. The questioning takes the form of initially asking a concept question and following the subsequent responses with parallel questions (Berry and Graham, 1991; Rowlands et al. 1999). How concept and parallel questions are employed is briefly illustrated in the next section. The examples are instances taken from one-to-one Socratic interviews of a cohort of A-level mechanics students and foundation year engineers who are studying mechanics (McWilliam, 2002).

The research undertaking is vast and we are only at the initial stages. It is anticipated that the research will be able to discern pre-formed elements in spontaneous reasoning and will be able to explain the dynamics of conceptual change. So far we are developing the method of concept and parallel questioning and the following are examples of the use of that method.

CONCEPT AND PARALLEL QUESTIONS IN THE ONE-TO-ONE CONTEXT.

A question is asked and the response reveals the sense made of the question. If the response is contrary to the Newtonian explanation, then the subsequent questions attempt to create cognitive conflict. If it is suspected that the response is a correct learnt response, then asking a parallel question might reveal this, and this is illustrated below. Spontaneous responses tend to be specific to the question, or rather, to what is perceived as 'standing-out' in the context presented by the question (*dominant features*. See Rowlands et al. 1999). Parallel question are questions that may relate to different scenarios (different phenomena or different though-experiments) but which have the same explanation as to the answer to the original concept question. The idea is for the student to realise the coherence and consistency of the Newtonian system in its explanation of diverse scenarios compared to the inconsistency, incoherence or situation-specific context of his or her reasoning. Student reasoning is an attempt to make sense and out of that reasoning ideas may be formed or defended which become *intransigent* simply because of the cognitive strain in making sense (Rowlands et al. 1999). One of the aims of the research is to promote cognitive conflict so as to examine intransigence in the light of anomalies. This is similar to the Posner et al. (1982) model. The difference is that we do not assume 'misconceptions' constitute in any way a pre-formed 'paradigm' of alternative beliefs, but arise spontaneously in response to the question.

The interviews were semi-structured in that 'templates' of concept question, parallel questions and anticipated student responses were made prior to the interview. The interviewer was allowed to deviate from the template according to the response of the student, but the logic of the template was adhered to. The following are from the transcripts and are chosen to illustrate the method.

- Critical moments: long pauses and facial expressions of cognitive conflict

Teacher: So I put the ball on the table, with the straw I give a quick blow. What happens?

Student: (*Paus*e) It will accelerate then decelerate.

Teacher: It will accelerate then decelerate?

Student: (*Interrupts*, *frowning*) Oh it's not affected by air resistance is it. It will go at constant acceleration. (Does he mean acceleration?)

Teacher: So it will accelerate constantly and just keep accelerating?

Student: Yes. (*Still frowning*)

Teacher: If you fire an arrow in empty space what happens to the arrow once it has left the bow? I'm in empty space and I fire an arrow. What happens to it?

Student: It will accelerate then go at constant speed.

Teacher: Right, it will accelerate initially while it is being shot out of the bow and then it will go at constant speed. So what's going to happen to a ping-pong ball?

Student: Oh right. Yes. (*Leans forward, clicks fingers*) Same thing. *(Critical moment)*

Further in the interview, the teacher asked questions concerning different examples that have the same explanation. The teacher was rather like Socrates asking loaded questions in the *Meno*, but the idea is to move the student towards a Newtonian understanding and to see how the student responds to the mediation.

- Vigilance for the provision of the 'right' answer where understanding was clearly not present

Teacher: Two similarly shaped masses of 1 kg and 2 kg are dropped simultaneously from equal heights onto level ground. Ignoring any effects from air resistance, which hits the ground first?

Student: Should hit at the same time.

Teacher: They should hit at the same time. OK, but surely the force (weight) acting on the 2kg mass is greater than the force acting on the 1kg mass. Are you sure they hit the ground at the same time?

Student: It's still equal.

Teacher: What's still equal?

Teacher: Can you explain why they (the forces) are still equal?

Student: Doesn't matter what the mass is. They're both acceleration in gravity.

Teacher: Are you saying your answer as an answer you know to be right?

Student: Yeah.

Note the leading question. Leading questions can verify the interviewer's interpretation and does not necessarily reduce its reliability (Kvale, 1996). This is especially true of conceptual change if the aim of the research is to see how students respond to the mediation of asking such questions, rather than such questions revealing previously held misconceptions.

The concept and parallel question in the next example aimed to challenge the misconception that gravity affects horizontal velocity. The concept question involves a car driven over the edge of a horizontal cliff at the same time and at the same velocity as a car that emerges from a tunnel at the base of the cliff vertically below. Air resistance is to be ignored. The student initially argued that the car at the top of the cliff will not land on the top of the car emerging from the tunnel. The parallel question (taken from Galileo) involves a sailor at the top of a mast dropping an apple. The ship's velocity is a uniform 15 knots and the question is, will the apple land behind, in front or at the foot of the mast? Through Socratic dialogue the parallel scenario can be understood. It was hoped that this would prompt a change of schema allowing the student to correctly answer the concept question.

Teacher: What was the horizontal velocity of the apple before it was dropped?

Student: Zero.

Teacher: Zero?

Student: Oh, fifteen knots.

Teacher: Fifteen knots. O.K. If it lands behind the mast its horizontal velocity must have changed, so it must have decelerated. What force is responsible for this acceleration?

Student: Gravity.

Teacher: What direction does gravity act?

Student: Oh that'd be going down wouldn't it. Air resistance.

Teacher: "Ignoring any air resistance"

Student: Oh right. Erm…(*Pause. Critical moment*)

Teacher: Is there a force that slows it down horizontally?

Student: No.

Teacher: There isn't. So what do you conclude from that?

Student: It drops and falls at the foot of the mast.

Teacher: It falls at the foot of the mast. Right. Back to the first question. Where will the car that has come off the cliff land with respect to the car coming out of the tunnel?

Student: On top of the car.

The next stage of the research is to discern pre-formed elements in spontaneous reasoning, whether those elements are the results of exposure to instruction, making sense of the physical world (such as the memory of applying a constant push to a large box to maintain uniform motion) or the use of force as a metaphor (e.g. regarding the inability to move a large box as not being forceful enough). One of the aims of the research is to see how Socratic questioning can be employed in the classroom setting. We will be publishing our results as the research continues.

NOTES

1. The term 'misconception' is controversial and many researchers prefer to use other terms that reflect their approach to the question (and their pedagogic disposition). The issue is complex because 'misconception' implies a *concept* that is wrong in relation to Newtonian mechanics. We will argue that 'misconceptions' may not be concepts, although some of them may be judged right or wrong. This is not to imply that judgement ought to be dismissive, or that the correct notion is to replace the incorrect notion. A misconception can be used as a teaching aid, such as 'that is not the right answer, but it is a *good* answer

because that was the answer given by Aristotle and accepted for two thousand years until challenged relatively recently by Galileo', etc.

2. Which is still very important information for the teacher.

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