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WHAT IS CONCEPTUAL CHANGE IN MECHANICS?

Stuart Rowlands and Ted Graham

Centre for Teaching Mathematics, University of Plymouth

Although conceptual change theory is a vast and well-established field of research and has provided many insights into the nature of student intuitive ideas, especially in mechanics, nevertheless it is still not clear as to what these intuitive ideas are and what happens when these ideas are supposed to change. With reference to schema theory, this paper sets forth the argument that intuitive ideas of force are not pre-formed but arise spontaneously in response to considering force and motion within its scientific context for the first time. This paper also puts forward the argument that we may have no choice but to look at pre-instructed concepts through the lens of the subject as a system of well-defined concepts.

INTRODUCTION

Conceptual change is the leading field of research in science education and its domain is extending to other subject areas such as mathematics and religious education. Research into conceptual change began in the 1970's with what may be described as the 'misconceptions literature' with mechanics in particular. The misconceptions literature found that, cross-culturally and across the age range, including physics undergraduates, many students exhibit intuitive beliefs regarding force and motion that are at odds with the concept of force in Newtonian mechanics. Many misconceptions of force can be classified as either the Dominance Principle (the larger mass imposes a larger force on the smaller mass) or the Impetus Principle (force is a property of an object), (Hestenes, 1992). Crudely speaking, a conceptual change theory is one that describes the nature of these intuitive concepts ('misconceptions') and prescribes ways in which these concepts can change/modify/evaporate in the light of the scientific concept. The most influential theory is the original conceptual change theory of Posner et al. (1982), which has become embedded in psychology and education textbooks, such as Howard's (1987) excellent coverage in his *Concepts and Schemata*. The theory viewed conceptual change as a (Kuhnian) paradigmatic change from intuitive concepts to the scientific framework. According to the theory, change can occur by the creation of cognitive conflict through the presentation of anomalies.

The original theory of Posner et al. has been very fruitful in understanding the nature of intuitive concepts and how these concepts can be 'tackled' in the attempt to move the student towards an understanding of the subject. Many theories since then, including Strike and Posner's (1992) "Revisionist Theory", have also been fruitful. However, despite the conceptual change literature's long history, the question 'what changes in conceptual change?' has yet to be satisfactorily answered and only recently have there been attempts to answer this question.

This paper is an attempt to go some way in answering this question, and argues that 1. Intuitive concepts may not be concepts and may not be pre-instructed, but arise spontaneously in response to considering a scientific concept within its scientific context for the first time, and 2. We may have no choice but to look at intuitive concepts through the lens of the subject as a *system* of well-defined concepts.

WHAT IS CONCEPTUAL CHANGE? FROM SPONTANEOUS IDEAS TO A SYSTEM OF CONCEPTS

> The questions about stability, coherence and universality of misconceptions in the domain of science are still unanswered. Some theoretical models of conceptual change have tried to describe features of this prior knowledge, but there is a lack of precision, in our view, to clarify what we are talking about – ideas, beliefs, theories, misconceptions, preconceptions, mental models, students' misunderstandings or failures to learn something. (Limón 2001, p.367)

The aim of conceptual change theory is to capture and model the *shifting* event (Caravita, 2001) and one of the fundamental issues is what changes when conceptual change occurs (Tynjäjä et al. 2002); yet after nearly three decades the question 'What changes?' has yet to be answered. Perhaps the biggest difficulty in answering this question is that what changes may be interpreted in different ways according to what model defines the structure of intuitive concepts, such as, for example, Rumelhart's schemata, Johnson or Vosniadou's mental model, Carey's domain-specific theories or Chi's ontological categories (Mason, 2001). Unfortunately there is no space to give a review that would do justice to the various models that have developed recently. Needless to say, however, that many of these models have not examined the logical structure of a system that is presumably the culmination of conceptual change (with notable exceptions, such as Hestenes, 1992; Halloun, 1998, for example). Using the example of mechanics education, it will be argued that an understanding of the subject as a system of concepts will enable to put into perspective the nature of intuitive concepts and the nature of conceptual change.

To throw light onto the nature of student conceptions of force and motion, Nikolaou and Watson (2004) raises Vygotsky's distinction between thinking in concepts and thinking in 'complexes'. Thinking in concepts is thinking of concepts within a system of concepts, such as performing a geometrical classification task by thinking of triangles, quadrilaterals, pentagons, etc. as distinct 3, 4 and 5 sided shapes. With thinking in complexes, such a task can be performed by discerning the perceptual features between the three, four and five-sided shapes etc, although mistakes are easily made when, for example, an isosceles trapezium looks almost like a triangle (Nikolaou and Watson, 2004). Using Vygotsky's distinction, Nikolaou and Watson have found that 'misconceptions' do not constitute thinking in concepts but are instead fragmentary ideas that do not admit to any hierarchical order and the meanings of which are contextualised with reference to what the student deems the salient features. Nikolaou's study attempts to see how Vygotsky's theory of concept formation can apply to 'misconceptions' of force and motion and the fruitfulness of the study may well lie in showing how 'misconceptions' can be modelled, not as concepts, but as intuitive responses that have a spontaneity in their formation. The idea of 'misconceptions' arising through spontaneous reasoning goes back to Viennot (1979, 1985) and may well be the key to understanding conceptual change.

It has often been presumed that 'misconceptions' are something that the pre-instructed student has formed prior to instruction and carries with her into the classroom (for example, Biemans et al, 2001; Bliss and Ogborn, 1994; Caravita, 2001; McCloskey et al. 1980; Duit, 2002; Mason, 2001; Mildenhall and Williams, 2001; Vosniadou et al. 2001). With reference to the literature prior to 1992, Orton states that "our experiences of force and motion throughout life lead us to draw conclusions which may be incorrect. *Intuitive beliefs extracted from our own experiences* explain mechanics for us in a way which we find acceptable and perhaps even helpful, but they may be wrong" (Orton, 1992, p.22, emphasis added). Since the 'revisionist theory' of Strike and Posner (1992), who stated

> [I]t is very likely wrong to assume that misconceptions are always there in a developed or articulated form during science instruction. This conclusion may be wrong even in those cases where widespread misconceptions have been documented. Misconceptions may be weakly formed, need not be symbolically represented, *and may not even be formed prior to instruction* . . . (Strike and Posner, 1992, p.158, emphasis added).

there has been a social constructivist/sociocultural trend that has regarded student conceptions as socially situated within the everyday and that the instructors job is not to challenge these conceptions but to enable the student to contextualise the concept with respect to its appropriate scientific domain (e.g. Linder, 1993; Kuiper, 1994; Driver et al. 1994; Mortimer, 1995; Leach and Scott, 2003). The point is, whether the conceptual change model assumes that 'misconceptions' or intuitive beliefs arise out of the child's interaction with the physical world or, alternatively, as 'ways of speaking' within appropriate or inappropriate domains, nevertheless there seems to be an almost unanimous agreement that these conceptions are fairly well formed prior to instruction and are theory-like. However, if that is the case, then these theory-like conceptions ought to be consistent in the way they determine observations and reasoning, but the evidence suggests otherwise (Halldén and Strömdahl, 2002). It has been argued that students' conceptions are consistent (hence having a coherent internal structure), although this consistency is affected by contextual parameters such as the context of the question (e.g. Palmer, 1994). But then, if consistency is affected by contextual parameters, why assume students' conceptions are consistent in the first place?

Strike and Posner's revisionist theory challenges the idea that 'prior conceptions' are theory-like in the Kuhnian sense. This implies that it is very unlikely pre-instructed students will bring into the classroom an intuitive but explicit 'framework' of force and motion. A 'misconception' does not imply concept possession, let alone an alternative concept-map. If misconceptions may not even be formed prior to instruction (Strike and Posner, 1992) then it may well be the case that misconceptions of force and motion are not formed until the student considers force in a scientific context for the first time. What is being suggested is that misconceptions have a spontaneity situated within the learning context. Of course, a response may contain elements of pre-formed ideas, such as those constructed from making sense of a previous lesson, or the memory of having to continually push a heavy box so as to maintain motion, or the ‘force’ of an argument changing someone’s position. Research ought to *discern* these elements, *rather than merely assume misconceptions are pre-formed ideas*.

The central question, ‘how can conceptual change theory capture and model the shifting event?’ presupposes a host of other questions, such as ‘what is a concept?’ what does ‘conceptual’ mean and is there a ‘shifting event’? Indeed, for diSessa and Sherin (1998), there is no conceptual change whereby intuitive ideas are replaced by scientific ideas; rather, these intuitive ideas are refined and developed through learning. Unfortunately, these questions require an extensive review of the literature suitable for a book. Without undermining the need for such a review, however, perhaps we can frame the central question the following way: how can we model conceptual change as a dynamic process, that is, as a change from spontaneous ideas to understanding the structure of the Newtonian system and the way the system can be brought to bear on the physical world? Conceptual change can be viewed (and perhaps can only be viewed) as part of the learning process and a model of conceptual change ought to include the learning situation and the method of teaching. However, any such model should also ‘capture’ and put into context the formation of ‘misconceptions’ (intuitive responses) and how these misconceptions change in the light of instruction. Schema theory may the most appropriate theory to account for the formation of misconceptions in terms of spontaneous reasoning situated in learning/teaching mechanics. Howard (1987) has provided an extensive introduction to schema theory and the following is a very brief description taken from his book. A schema may be defined as a cluster of related concepts that help us make sense of the world; for example, *face* is not only a concept (part of the human body) but is also a schema that helps us organise how the concepts of *eye*, *mouth*, *ear* and *nose* are arranged. A schema consists of a set of expectations about how parts of the world are organized. For example, if we walk into a dark room and see a pair of eyes then we would *instantiate* our *face* schema. A schema has *slots* or *variables* that are filled with concepts and are organised in a certain way. Most schemata are often hard to ‘dislodge’ as a consequence of their function as a filter: once we feel that the world is organised in a certain way then we are reluctant to abandon that view. Discrepant data is therefore either ignored or the data changes the schema in idiosyncratic ways.

According to Rowlands et al. (1999), the student who is asked to account for motion in terms of force might slot ‘force’ into her schema instantiated to account for the motion in some way and the slotting in of ‘force’ will depend on the way the student conceives the motion (e.g. for a thrown ball, a force is ‘required’ to push the ball in order to overcome gravity; to maintain circular motion, there 'must' be a force that acts radially outwards). *If a schema of motion is instantiated with force as one of the slots, then the definition of the student's intuitive concept of force is dependent upon its relation to the other slots in the schema*. For example, if a student's schema of a thrown ball includes a force pushing the ball, then the definition of the student's concept of force in this instance is specific to that which 'overcomes gravity' to maintain motion (Rowlands et al. 1999). In other words, motion-of-objects schemata of uninstructed students are *situation-specific* (Champagne et al. 1982). This is not to suggest, however, that the student's schema of force and motion arises out of a vacuum. What may already exist beforehand is what Stinner (1994) refers to as a 'personal kinesthetic memory' upon which we base our 'commonsensical' notions of force. These personal kinesthetic memories are images of the experience of objects in motion and their evocation/instantiation may be something that is triggered by what stands out for the child/student/adult in situation specific reasoning. According to Rowlands et al. (1999), in situation-specific reasoning we tend to focus on the *dominant features* of motion ('up', 'down', 'moving horizontally', 'large body', etc.) and force as a concept is instantiated a number of different ways according to the various schemata of motion (personal kinesthetic memories) – *it is as if student reasoning tends to focus on the body in the context of motion (to which force is instantiated), rather than the motion in the context of forces acting on the body*. For example, Viennot (1985) found the common idea that the force acting on an object is proportional to its velocity occurs mainly when motion is a striking feature of the proposed physical situation. Fischbein et al (1989) found that the type of moving object was an important factor in student conceptions of motion.

Misconceptions tend to be context specific and it may well be the case that, for some students, several different contexts exhibit the same dominant feature which activates a particular kinesthetic memory. It is hoped that research will uncover these dominant features and what they activate.

MISCONCEPTIONS THROUGH THE LENS OF NEWTONIAN MECHANICS

If we consider schema theory to be an appropriate theory to explain the formation of misconceptions, then we have a means to contrast the intuitive idea of force with its scientific counterpart and how the former changes with respect to the latter. On the one hand the intuitive schemata of force and motion does not account for all different types of motion but are instead dependent on the dominant features of motion. On the other hand the Newtonian concept of force is implicitly *well-defined* by the laws of motion (Hestenes, 1992) and can account for different types of motion (projectile motion, circular motion, motion down an incline plane, free-fall, etc.) without having to change the definition of force (or, rather, what is to count as force) with respect to each type. There are many implications that follow from this and may perhaps throw light on the nature of conceptual change. For example:

- A ‘global’ taxonomy of student misconceptions may be impossible because the consideration of misconceptions requires a specificity regarding the context from which the misconceptions occur, such as what kind of problem prompted the misconception (Viennot, 1985). However, ‘local’ taxonomies of student misconceptions with respect to what dominant features prompted them may be possible. If so, then any consistency could be determined by contextual parameters.
- Misconceptions are resilient, not because misconceptions have been formed over years and years of experience, but because of the cognitive strain in forming an intuitive schema of force and motion to account for examples of force and motion the first time (Rowlands et al. 1999).
- A ‘Newtonian understanding’ of the force concept in the qualitative sense of understanding what forces are acting on which body would require the student’s appreciation that his or her intuitive schema of force and motion lacks the same consistency or coherence compared to the Newtonian system. Hence Hestenes’ (1992) proposed non-separation between ‘modelling games’ or ‘model centred instruction’ and the ‘evocation’ of misconceptions: different questions concerning different ‘scenarios’ or phenomena but *which all have the same explanation under the Newtonian system* can be asked so as to illicit inconsistencies in student reasoning. Of course, how students respond to their own inconsistencies is still speculation. Whether they make rapid attempts to correct their reasoning when they become aware of contradicting ideas (e.g. Minstrell, 1982; Hake, 1987; Marton, 1986) or they are intransigent (e.g. Howard, 1987; Viennot, 1979; Burbles and Linn, 1988) has yet to be ascertained. Of course, there are many factors involved here, such as motivation, but if conceptual change is situated within the learning context then one very large factor involved must be the *way* anomalies are used as directional signs and stepping stones towards understanding the subject.
- To involve the student with modelling games will necessarily require the student to think of abstract, ‘possible worlds’, which are impossible in the real world, For example, to ask the student how a stationary puck on a frictionless table can be given uniform motion. Students independently of whether they are concrete or formal thinkers can be invited to enter the ‘Newtonian world’ which provides the perfect opportunity to consider ‘if-then’ abstract possibilities that may well lie within their capabilities that may otherwise be restricted to the concrete.

CONCLUSION

A misconception may be a spontaneous response in attempting to provide an answer to a given question. Student reasoning in trying to defend the response might reveal components that can be said to be ‘pre-instructional’; what components may be evoked will perhaps be ascertained by a future model of conceptual change that looks for these components and examines them in the light of empirical research, *but within* *a framework that views conceptual change as a dynamic process of spontaneous reasoning as directed towards a conceptual understanding of the subject domain.*

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