# STUDENTS' CONCEPTIONS OF THE FORCES ACTING ON OBJECTS IN MOTION

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## ABSTRACT

Over the last two decades a great amount of educational research has focussed on the ideas which students have in relation to scientific concepts. It is now well established that during their experiences in everyday life children develop their own 'naive theories' which they use to explain the natural phenomena which they observe in the world around them. In this study, 275 Year 10 students from a range of schools in the Hunter area answered a questionnaire in which they were asked to draw and name the forces acting on a ball thrown vertically upwards well after it has left the hand. Just over 10% of these students were also interviewed. Ninety©five percent of the students correctly indicated the force of gravity and seventeen percent correctly indicated the force of air resistance acting downwards on the ball. However, 72% of the students indicated a force pushing the ball upwards © a conception which is scientifically incorrect. The results from interviews indicated that the majority of these students already had this notion of a pushing force before they learnt about science at school then they simply added concepts such as gravity and air resistance to their existing conception. The results thus supported a constructivist interpretation of learning in this topic.
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## ƒINTRODUCTION

Over the last two decades a great amount of educational research has focussed on the ideas which students have in relation to scientific concepts (see Driver, 1989). It is now well established that during their experiences in everyday life children develop their own "naive theories" which they use to explain the natural phenomena which they observe in the world around them. The existence of these ideas amongst students has been demonstrated in a wide range of sciences including physics, chemistry, biology, astronomy and earth science (see Osborne  Freyberg, 1985). In this paper, the term "alternative conceptions" will be used to describe these ideas.

One alternative conception which was identified over a decade ago is the idea that a continuous action of a force is necessary to keep an object in motion (Viennot, 1979). It soon became apparent that this idea predominated amongst both secondary

students (Watts and Zylbersztajn, 1981) and tertiary students (Clement, 1982). Early attempts were also made to pass on these findings to classroom teachers © the late Roger Osborne presented a keynote lecture to the 1981 Conference of the Australian Science Teachers Association which described secondary students' alternative conceptions of forces (Osborne, 1981), and similar points were made in science teachers' journals such as Physics Education and The Physics Teacher (e.g. Osborne, 1984; McClelland, 1985) and Scientific American (McCloskey, 1983). It is thus over a decade since researchers and educationalists became aware of students' difficulties in mechanics and in particular the "motion implies force" conception. During this decade, the process of informing teachers continued, with a number of authors both in Australasia and elsewhere reporting on this particular alternative conception in mechanics (e.g. Van Hise, 1988; Gunstone, 1990; Sadanand & Kess, 1990; Hestenes & Wells, 1992). One of the aims of this process is to communicate findings to teachers so that they can take these alternative conceptions into consideration as they are teaching and this will presumably result in a decrease in their occurrence. It is therefore of interest to determine the extent to which the students of today, who have learnt their science during the period following much of this work, continue to hold this alternative conception.

Another area of interest to researchers has been the consistency with which students answer questions about mechanics. The study of consistency and the factors affecting it are important for two reasons. Firstly, from a theoretical point of view, it indicates the extent to which students' conceptions are genuinely theory©like in that they  have "a coherent internal structure" (Driver, 1989). Secondly, one of the oft©stated aims of science education is that students will be able to use science to understand the world around them. It is difficult to see how students will achieve this if they do not have the ability to generalise principles to a range of relevant situations. Thus it is important to understand the factors which affect the ability of students to generalise their conceptions even though these conceptions may be at odds with accepted scientific viewpoints.

It appears that the context of the question plays a large role in affecting the consistency of students when answering questions in mechanics. For example, when dealing with different types of motion (ie. linear, projectile and periodic motion) many students answer some questions in one way and other questions in other ways (Halloun & Hestenes, 1985; Finegold & Gorsky, 1991). Some other critical contexts have also been identified. For example, Chi, Feltovich & Glaser (1981) found that novices tended to classify mechanics problems according to the types of physical objects which were in the questions. Fischbein, Stavy & Ma©Naim (1989) and Whitelock (1991) studied students' conceptions of motion and found that the type of moving body was an important factor for some.

It is possible that these are not the only contextual parameters which impinge on students conceptions of forces and motion. For example, very little attention has been paid to factors such as the speed of the motion © fast versus slow.

The aims of the present study were therefore:
to serve as a replication study concerning the prevalence of this alternative conception; and
to investigate whether the speed of the motion is a contextual factor which influences students' responses.

For the purposes of this study the alternative conception is stated as being that "if an object is in motion then there is a force in the same direction as the motion".

ƒMETHODOLOGY

The instrument

This study used a survey approach supplemented by individual diagnostic interviews. The relevant questions used in the survey are presented in the Appendix. The survey also contained some other questions on mechanics which were not relevant to the research questions addressed in this paper.

In previous Australasian studies, the "motion implies force" conception has often been identified in target populations by using an item concerning a ball being tossed vertically and illustrated with a stick figure diagram (e.g. Osborne, 1981; Gunstone, 1990). It was therefore decided that the situation of a ball rising vertically would form a suitable context for comparison with earlier studies. Question 1 in the instrument was constructed on this basis.

Question 3 also concerned a ball moving vertically upwards but the implied rate of motion was "slow" whereas in Question 1 it was "fast". Questions 2 and 4 were designed to provide complementary written explanations to the situations presented in Questions 1 and 3.
Questions 7 and 8 concerned balls moving vertically downwards and were included to clarify the nature of some of the responses (as explained in the results). The questions were validated (for readability and ambiguity) by two physics lecturers.

The sample

The survey was administered to 275 Year 10 students (15©16 year©olds) who came from eleven schools which covered a range of socioeconomic conditions in the Newcastle area. One whole science class participated from each school. The classes represented a range of achievement levels (ie. classes streamed as upper ability, middle ability and lower ability, as well as unstreamed classes). Care was taken to mix the class types and the socioeconomic areas. For example, upper ability classes came from both upper and lower socioeconomic areas.

All the students were about to finish their final year in which science is a compulsory subject and all had completed introductory units on forces and motion.

Procedure

Students were asked to complete the survey during their normal science classes, but they were informed that it would not contribute towards their school assessment in any way. After each class completed the survey, a small number of volunteers (representing just over 10% of the sample overall) participated in individual, audiotaped interviews. The interviewees were asked to describe and explain their responses to the survey questions and to describe (if they could remember) what their ideas had been before instruction.

RESULTS

Occurrence of a "motion force"

Generally, if the student, when responding to Question 1, drew an arrow in the direction of the motion of the ball then they were assumed to be indicating a "motion force" for that particular question. (The interviews indicated that this was almost invariably the case.) An important exception to this was if the student drew an arrow in the direction of the motion of the ball and labelled it with a term such as velocity, acceleration, kinetic energy, inertia or momentum which may have represented either a misreading of the question or a use of the term to name a "motion force". In order to solve this dilemma, Questions 7 and 8 were referred to. The former concerned a ball which had been thrown vertically downwards and in the latter the ball had simply been dropped. Those people who used a term such as velocity, acceleration, kinetic energy, inertia or momentum in Question 7 but not Question 8 were assumed to have the alternative conception. This assumption was supported by the interview data. The responses of those students who used the term in both questions or whose responses were uninterpretable were considered to be inconclusive.

This system of coding was tested using a two step process of agreement which was carried out between the author and a lecturer in physics. In the first step, a representative sample of 10 completed surveys was independently examined and agreement using this system of categorisation was found in 8 of the 10 cases. After discussion and resolution of the discrepancies another representative sample of 10 completed surveys was examined and agreement was found in every case.

The responses of each student to Questions 1 and 2 were categorised according to the above format in order to determine the proportion of students whose responses indicated the alternative conception. A force in the same direction as the motion was indicated by 72% of the students; it was absent in 7% of the students; and 21% of responses were inconclusive for the presence of a "motion force".

The written explanations of the majority of the students supported the interpretation of a force in the direction of the motion. For example, one student, in answer to Question 1, had drawn an arrow in the direction of the motion and had labelled it "applied force"; in answer to Question 2 the student then wrote "gravity was acting on the ball forcing it downwards as the applied force was forcing it upwards. as the ball travelled higher the applied force grew less and gravity forced the ball downwards." Other representative responses included "the force exerted by the person is becoming less as gravity is taking over.." and "The force from the hand diminished as the force of gravity started to take over".

The great majority of the students indicated an understanding of a retarding force which opposed the motion of the ball © 90% of the students indicated the force of gravity, and 17% indicated air resistance. However, a small proportion (5% of the group) appeared to consider that the ball slowed down as its motion or "motion force" became depleted spontaneously (ie. not due to

external influences). Their written explanations typically included statements such as "because there was no more force behind ie you can only supply a certain amount of force to something and eventually it will run out", "The force diminished that kept the ball moving", and "because it lost its force and started to go down".

Interestingly, 81% of the students who included air resistance came from classes streamed as "top" classes, but the great majority of them still included a motion force as well.

Conceptual development

Each student who was interviewed was asked if their answer to Question 1 would have been any different before they learnt about forces at school. The results are shown below.

TABLE 1
YEAR 10 STUDENTS' DESCRIPTIONS OF HOW THEIR CONCEPTIONS OF FORCES IN QUESTION 1 HAD CHANGED SINCE SCHOOLING

| description | number |
|---|---|
| no change / can't say | 13 |
| upwards force before, then upwards and/or downwards after | 17 |
| downwards force before, then upwards and downwards after | 1 |
| no forces before, then upwards and downwards after | 1 |

The results indicate that the majority of the interviewees could remember (correctly or incorrectly) having changed their ideas. Of those whose ideas appeared to have changed, the majority started with a "motion force" and then added the downwards forces as they learnt about forces at school.

Differences between fast and slow

Responses to Questions 1 and 2 were compared to responses to Questions 3 and 4. Any differences were noted except where one or both of the questions had an uninterpretable answer. Only three students (representing 1% of the sample) indicated a qualitative difference with regard to the existence of a "motion force". Two of these students included a "motion force" in Question 3 but not Question 1, whereas the remaining student drew a "motion force" in Question 1 but not Question 3. However, their written explanations (Questions 2 and 4 ) were inconclusive in support of this difference. In conclusion it appears that very few, if any, of the students considered the implied speed of the object to be a factor determining the existence of  the alternative conception.

However, some students offered explanations in Question 4 which intimated that the ball didn't go as high because the "motion force" was less. For example "there was not as much force pushing the ball upward so it slowed down a lot quicker". These students obviously deemed the questions to be quantitatively different with regard to a "motion force", as might have been expected.

A total of six students (2% of the sample) described air resistance as present in one question but not the other.  However, none of the explanations gave any reason for this. Five of these students

included air resistance in Question 1 (the fast moving ball) but not Question 3 (the slow moving ball) so it is possible that they were discounting it as being irrelevant in the case of the slow moving object.

All the students who indicated the force of gravity in Questions 1 and 2 also included it in Questions 3 and 4, and vise versa. Thus, there was no evidence that the implied speed of the motion affected the students' conception of the force of gravity.

DISCUSSION

In this study, the proportion of people who were identified as having the alternative conception was over 70%. This is comparable or slightly higher than the results of previous Australasian studies. For example, Osborne (1981) found that 66% of 15 year©olds held this view, and Gunstone (1990) found that 63% of the 15©16 year©olds in the Australian sample held this view. However, it is slightly lower than in some non©Australasian studies © Watts & Zylberasztajn (1981) and Sadanand & Kess (1990) reported levels of 85% and 82% respectively. It is difficult to tell whether these differences are significant as the question formats were slightly different in each case and because the present study returned a relatively large proportion of inconclusive responses (21%) some of which may have had the alternative conception. This level of inconclusive response, while large, is not atypical of studies using this type of open©ended diagrammatic question (Gamble, 1989).

However, the present results do indicate that in spite of the efforts of teachers and educational researchers over the past decade, the proportion of these Year 10 students holding the alternative conception remains disturbingly high. Whilst it is of some concern this result is not surprising © research indicates that this alternative conception is often very strongly held and that conventional science lessons at school often fail to change it. McCloskey (1983) tested the knowledge of motion amongst high school students before and after they had finished a physics course and found that "the course had left some misconceptions unaffected. The instruction was particularly unsuccessful in altering the core assumption that impetus acquired when an object is set in motion serves to maintain the motion: 80 percent of the students retained this belief even after finishing the course. (Ninety three percent held the belief prior to instruction.)" Clement (1982) found that 75% of a group of university students still indicated a force in the direction of the motion after tertiary instruction in mechanics. Even courses which are specifically designed to change this conception may have limited success (Thijs, 1992). The complexities of conceptual change in mechanics have been well documented (e.g. Mestre & Touger, 1989; Brown, 1992; Gunstone, Gray & Searle, 1992), but the extent to which secondary science teachers are actually employing conceptual change techniques is as yet unclear.

The majority of the interviewees in the present study described a conceptual development in which their initial idea was that of a "motion force" and they then added concepts such as gravity and air resistance which they learnt about at school. Nussbaum (1989) proposed that learning in science "forms an evolutionary pattern in which the student maintains substantial elements of the old conception while gradually incorporating individual elements from the new one". The results from the present study suggest that for some students, the development of mechanics concepts occurs in just such a way. The fact that these students had incorporated what they had learnt at school into their existing conception of a "motion force" rather than just rejecting their existing conception can also be interpreted as supporting a constructivist view of learning. In other words, the learner constructs cognitive structures out of his/her experience and as these make logical sense to the learner he/she is unwilling to part with them (Saunders, 1992).

## Conclusions and Implications

It appears that very few, if any, of the students were influenced by the contextual parameter of the implied speed of the moving object when answering these questions on linear motion. This suggests that the implied speed of the motion is not a contextual factor which is of any significance with regard to the existence of the alternative conception, at least in the narrow range of situations presented in this study.

There is no evidence that the efforts of educational researchers and teachers over the past decade have resulted in a more scientific understanding of motion amongst these students. We clearly have a long way to go towards a resolution of this problem.

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APPENDIX

The test questions are presented below, without their accompanying diagrams.

1.Imagine that you have just thrown a tennis ball as hard as you can, straight upwards into the air. Draw and name the force or forces, if any, acting on the ball as it is still moving upwards quite quickly, well after it has left your hand.

2 Explain why the ball (in Q1) slowed down as it got higher.

3.Imagine this time that you have tossed the tennis ball very gently upwards, so it only goes up a short way. Draw and name the force or forces, if any, on the ball as it is still moving straight upwards after it has left your hand.

4.Explain why the ball (in Q3) slowed down as it got higher.

7.Imagine that you are standing on a table and you have just thrown a tennis ball as hard as you can straight downwards to the floor. Draw and name the force or forces, if any, on the ball as it is still moving straight downwards, well after it has left your hand.

8Imagine that you are standing on a table and you have just let a tennis ball drop by itself to the floor. Draw and name the force or forces, if any, on the ball as it is still moving straight downwards, well after it has left your hand.