International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713737283

Alternative frameworks: Newton's third law and conceptual change

Colin Terry [a]; George Jones [a]
[a] University College of North Wales, Bangor, UK

Online Publication Date: 01 July 1986

To cite this Article Terry, Colin and Jones, George(1986)'Alternative frameworks: Newton's third law and conceptual change',International Journal of Science Education,8:3,291 — 298

To link to this Article: DOI: 10.1080/0140528860080305

URL: http://dx.doi.org/10.1080/0140528860080305

EUR. J. SCI. EDUC., 1986, VOL. 8, NO. 3, 291–298

Alternative frameworks: Newton's third law and conceptual change

Colin Terry and George Jones‡, University College of North Wales, Bangor, UK

Pupils' alternative frameworks and misconceptions about force and motion have been widely reported. The various investigations clearly show that children have difficulty in applying Newton's first and second laws to everyday situations. This report highlights some of the difficulties that children experience with Newton's third law. It suggests that we should be more concerned with children's overall understanding of the concept of force and that this understanding is underpinned by an understanding of the third law. Suggestions are made for promoting conceptual change based on a model first proposed by Posner *et al.* (1982).

Introduction

Numerous studies have shown that students over a wide range of age and educational background harbour basic misconceptions which interfere with their understanding of many aspects of mechanics (Clement 1982, Viennot 1979, Watts and Zylbersztajn 1981). Central to many of these studies has been the exploration of students' alternative frameworks of force and motion. There is no doubt that students experience conceptual difficulties with Newton's first and second laws. Warren (1979) argues that the way in which these concepts are presented in textbooks (and consequently taught by teachers) contributes to these difficulties. For example, he suggests that some of the attempts that are used to help students understand the quantative relationship expressed in the second law, promote the association between motion and a force in the direction of motion, thereby increasing the difficulties involved in understanding the first law. At a more advanced level, Warren suggests that in a given situation students are not certain what forces are acting, by what mechanism they act, or indeed where they act. Confusion between the forces acting on different bodies often arises from a misunderstanding of the third law and this in turn contributes to their conceptual difficulties with the second law. Clearly for students to obtain a satisfactory understanding of the concept of force, they must have a clear understanding of all three laws and appreciate the relationship between them. Hence any efforts that are made to improve students' conceptual understanding should

‡ Present address: Ysgol David Hughes, Menai Bridge, Anglesey, UK.

be concerned with changing their overall framework of the concept of force. The majority of the investigations into students' understanding of force and motion have focused on Newton's first and second laws. The aim of this study was to investigate some of the conceptual difficulties that students find with the third law and examine the implications that these may have for bringing about a change in their overall understanding of the concept of force.

Previous studies

As part of a wider survey of young children's ideas about force Watts and Zylbersztajn (1981) presented the pupils with a series of questions about a tug-of-war situation. Perhaps not surprisingly, a large majority of the children was unable to describe the situation satisfactorily in terms of the forces involved in the interaction. For example they were unclear about the direction of the forces exerted on or by the rope and/or the people who were tugging on it. In a study concerned entirely with Newton's third law, Maloney (1984) investigated students' understanding of the interaction between two blocks which were in contact with each other and which moved with constant acceleration. Of those students in the sample who had completed a high school physics course, very few were able to successfully analyse the situations presented to them in terms of Newton's third law.

The present study

The purpose of the study described here was to examine the difficulties faced by 16-year old pupils who had recently completed an O level course in physics. The pupils were asked to interpret in terms of Newton's third law, a variety of situations in which two objects interact with each other. The tasks consisted of a series of drawings which depicted situations to which the pupils were asked to respond.

The first four problems were designed to obtain an overall view of pupils' understanding of the third law. The first question was concerned with the static situation. The picture showed a person standing on the ground and the pupils were asked to identify the Newton third law force which is 'paired' with the weight force (figure 1a). Only two pupils out of the sample of 39 correctly identified this as the force exerted by the person on the earth. Over two-thirds of the remainder identified the force as that exerted on the person by the ground. In the second problem the pupils were shown a stone falling freely under gravity (figure 1 b). Once again they were asked to identify the force that is paired with the gravitational force of the earth acting on the stone. Only four pupils responded correctly to this question. Of those responding incorrectly, about half of the sample cited air resistance as the paired force. The next two questions asked pupils to predict the outcome of situations where two objects interacted with other. In the first problem, the diagram showed a pair of magnets being used in an attempt to get a vehicle to move (figure 2 a). The pupils were asked to discuss whether the vehicle would move or not. About 90% of the sample thought that the vehicle would move and gave as their reason the attractive force between the two magnets. Question four was similar to question three. It showed two people standing

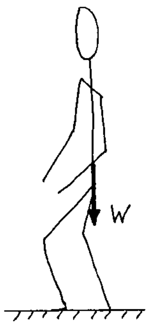

Figure 1 a.

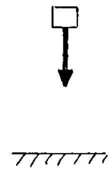

Figure 1 b.

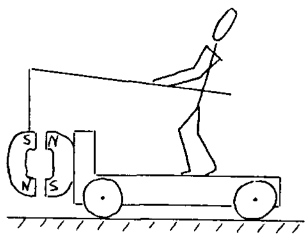

Figure 2 a.

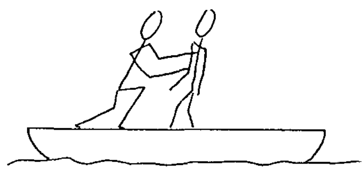

Figure 2 b.

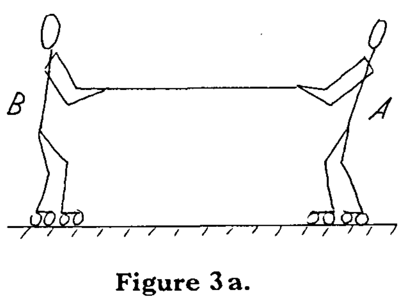

Figure 3 a.

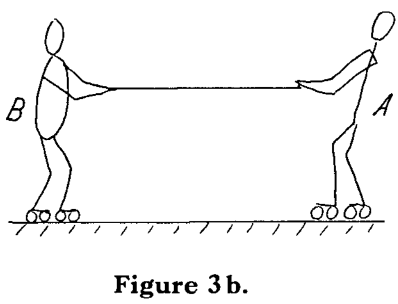

Figure 3 b.

in a boat and the pupils were asked to explain what would happen to the motion of the boat if one person pushed on the other (figure 2 b). About 15% of the sample responded correctly to this question.

The remaining problems examined pupils' understanding of the interaction forces between two objects of unequal mass. Question 5 showed two roller skaters, *A* and *B* of equal mass connected by a rope (figure 3 a). The pupils were asked to describe what would happen if *A* only pulled in on the rope. Over 90% of the sample correctly predicted that both the skaters would move towards each other. But when they were confronted with a situation in which the mass of *B* was clearly greater than that of *A* (figure 3 b), about half of the group stated that *B* would remain stationary and *A* only would move. Question 7 was similar to question 6 – it asked the pupils to compare the impact forces when an insect hits the windscreen of a moving car. About 60% of the sample thought that the force exerted by the windscreen on the insect would be larger than the force exerted by the insect on the windscreen.

A summary of the results of this investigation is shown in table 1.

Discussion

The problems presented to the pupils can be categorized according to the details of response needed to correctly answer the questions. In problems 1 and 2, the pupils were informed that they should use their knowledge of Newton's third law to answer the questions. Consequently these two problems required that the pupils correctly identify the 'missing' force of the third law pair.

Pupils seem very unclear of the forces involved in a simple case of static equilibrium. There appears to be a very common misconception that the two

Table 1. Percentage of pupils responding correctly to questions involving Newton's third law.

Question	*Situation*	*Response required*	*Correct responses* (%) $n=39$
1	Static equilibrium	Identify 'pair' force	5
2	Stone falling under gravity		10
3	Vehicle and magnets	Predict motion	10
4	People in boat		15
5	Skaters—equal mass	Compare interaction forces	90
6	Skaters—unequal mass		50
7	Insect on windscreen		40

forces of a third-law pair act on the same object to keep it in equilibrium. This result can be compared with an earlier study of static equilibrium (Terry *et al.* 1985) in which younger children thought that only one force acted on a box at rest on table – the downward force due to gravity. But older pupils who had been taught Newton's third law cited this as the reason that the object was in equilibrium. This type of misconcept is confirmed by the second problem which showed a stone falling under gravity. Out of the 39 pupils in the sample, 17 were unable to suggest a force that could be paired with the pull of the earth on the stone. A further 18 pupils incorrectly identified air resistance as the appropriate force. Taken together, these two problems demonstrate that the pupils incorrectly interpreted Newton's third law. In providing the pupils with the questions, details of the force that was given in the question were clearly emphasized. For example, in problem 2, the question referred clearly to one force of the pair as 'the force *of* the *earth on* the *stone*'. This emphasis was clearly insufficient to prompt the pupils into giving the corresponding force *of* the *stone on* the *earth*. Where pupils attempt to identify a third law pair force, they do not see the need for the forces to act on different objects. This suggests that they do not have an understanding of the concept of force and interaction – they do not understand that forces arise from interactions between two objects or that the forces involved in the interaction can be described by the third law. There was no indication that pupils generally think of an interaction in terms of an equal and opposite pair of forces. Yet such an understanding is central to an understanding of the overall concept of force.

Problems 3 and 4 required pupils to predict the effect of easily identifiable interactions on the motion of objects that were free to move. In their study of physics, pupils have experience of magnetic forces and forces that arise from pushes or pulls. So in these questions, identification of the forces involved should not have presented any problem. In the question involving magnets, most of the pupils indicated a single force acting on the vehicle in the direction of the intended motion. This suggests that having identified the force exerted by one magnet on the other, they did not see the need to analyse the situation further. Once again, in questions 3 and 4 there was no evidence to indicate that the pupils interpreted the interactions in terms of a pair of forces. Problems 5, 6 and 7 required the pupils to compare the magnitude of the forces involved when two objects interact. The fact that 90% of the sample responded correctly to question 5 can probably be attributed to the use of this example to introduce Newton's third law. All the pupils had previously met the situation involving objects of equal mass. But the responses to questions 6 and 7 indicate the difficulty many of the pupils have when they are asked to analyse situations only slightly different to the one with which they are familiar. Discussions with some of the pupils who responded incorrectly showed that they were reluctant to compromise in their analysis of the unequal mass situation – only the skater with the smaller mass would move, even if the difference in mass between A and B was made smaller. The responses to question 7 showed that most pupils used a naive, intuitive approach to the problem, rather than interpreting the situation in terms of an interaction that could be described by the third law.

The results of this small scale survey indicate some of the difficulties that children experience in understanding the interaction between two objects. When they are confronted with everyday situations involving interactions, they are generally unable to interpret these situations in terms of Newton's third law. We suggest that this has implications for the development of an understanding of the concept of force. For example, it can lead to difficulties in identifying the forces acting in a given situation, and consequently hinder an application of the second law. Also, it is difficult to see how pupils can gain an understanding of momentum conservation without an understanding of the third law. Of course, pupils are usually 'told' that forces come in pairs but this survey suggests that this fact is often wrongly incorporated into their conceptual understanding of the first law rather than forming the basis of a correct understanding of the third law. How can we attempt to change this situation? Posner *et al.* (1982) have outlined the features of a model of conceptual change which is framed around two questions:

(*a*) Under what conditions does a student replace his/her current conceptual basis for understanding a phenomenon with a more appropriate conceptual understanding?
(*b*) What are the features of the student's conceptual make-up which govern the selection of new concepts?

Following Posner *et al.* we shall adopt the stance whereby a student's existing conceptual framework will be rejected only when it has generated or is confronted with a class of problems which it lacks the capacity to solve. An alternative conceptual framework will be accepted only if it appears to have the potential to solve this problem and lead to fruitful applications in other areas. Thus it would seem that the following conditions at least are necessary for a student to accommodate a new conceptual basis for understanding.

(1) There must be dissatisfaction with existing conceptions. A student is unlikely to be motivated to make the effort to understand a new concept unless he/she can see that it is likely to bring adequate recompense. If this is not seen to be the case, it is unlikely that the student's past and present experiences. Furthermore, it should fit
(2) The new concept must be intelligible. This entails not only an understanding of terms and symbols and syntax of the mode of presentation but also the construction of a coherent representation of the new concept (Bransford and Johnston 1973).
(3) The new concept must be plausible. It must not appear counterintuitive. For example, it must be seen to be consistent with the students' past and present experiences. Furthermore, it should fit into the student's overall view of the environment. As Papert (1980) says, it should be seen as a way to conceptualize the workings of physical reality.

Once the student has tentatively taken the new concept on board, then his/her early attempts to interpret experiences with it must be fruitful. If in addition, the new concept can be shown to be potentially useful in a variety of novel situations, then the student will be more likely to 'firm up' the concept and his/her accommodation will progress further. The adoption of the new concept is seen not as an immediate acceptance or rejection, but rather in terms of a gradual readjustment in the student's thinking to accommodate the new idea.

We have suggested that students will resist making changes unless they are dissatisfied with their current conceptual model of the situation. Anomalies or paradoxes can provide the necessary cognitive conflict situation which might pave the way towards an accommodation of the new concept. But as Posner *et al.* (1982) point out, when faced with an anomaly there are several alternatives open to the student of which the most difficult (and the one requiring the most effort) is a fundamental revision of existing conceptions. The student might well elect to follow an (easier) alternative route whereby he/she: (*a*) consciously rejects the observations which constitute the paradox; (*b*) compartmentalizes the new information so that it does not conflict with existing beliefs; (*c*) attempts to assimilate the new information into existing conceptions; (*d*) lacks concern for the new information on the grounds that it offers nothing new to his/her current conceptual thinking; or (*e*) lacks the motivation due to the conviction that what he/she is being offered is something that is not worth the extra effort needed for its understanding, a view that has been put forward in more detail by McClelland (1984). Thus providing a paradox or anomaly that generates the necessary cognitive conflict is of primary importance. As far as Newton's third law is concerned, there are many possibilities. For example, when a person on roller skates pushes *forward* against a wall, the effect on that person is a change of motion in the *backward* direction. This type of demonstration might be accompanied by an example of the violation of the third law that is often seen in cartoon films – a cartoon character sitting in a boat makes it move by blowing into the sail. The second stage of the accommodation process involves the intelligibility of the new concept. Warren (1979) maintains that the third law is misunderstood because textbooks and teachers usually present it in a form something like 'action and reaction are equal and opposite'. Warren suggests that the terms 'action' and 'reaction' imply a time-sequenced cause and effect relationship whereas the forces of a third law pair arise simultaneously from the same interaction. It is also likely that the use of the word 'opposite' suggests that the two forces must act on the same object and this is perhaps why many pupils associate the third law with the condition for equilibrium. So to present the third law in an intelligible way, we should avoid the use of the words 'action', 'reaction' and 'opposite' and instead provide a fuller and more meaningful statement of the law. Perhaps we should also provide an adequate explanation of how the forces of a third law arise. For example, we could discuss the origin of contact forces in terms of electrostatic repulsion. The next step is to ensure that the new concept has initial plausibility. As Posner *et al.* suggest, we can do this by: (*a*) relating the concept to the students' past experience; and (*b*) showing how the new concept is effective in resolving paradoxes similar to those used to establish the cognitive conflict in the early stages of introducing the concept. This can be related to the fourth stage in the accommodation process where the student becomes aware of the fruitfulness of the concept. It is when the new concept not only resolves existing anomalies, but also when it leads to new discoveries that it will appear useful. The third law can be shown to be useful in a wide variety of situations ranging from the motion of aeroplanes and helicopters to the derivation of the law of conservation of momentum.

Posner *et al.* caution against the assumption that because accommodation is a radical change, it must be abrupt. There are good reasons to suppose that it is a gradual and piecemeal process involving a gradual modification of existing ideas as the learner comes to terms with the meaning and implications of the new concept. The conceptual changes associated with an understanding of the third law should be viewed in conjunction with a change in the students' overall understanding of the concept of force. This will entail coming to terms not only with the third law but also with the first and second laws. The third law should be seen as an important component in the development of students' understanding of force, rather than be taught separately (and often later) than the other laws.

References

BRANSFORD, J. D. and JOHNSON, M. H. 1973, Considerations of some problems of comprehension. In W. G. Chase (ed.), *Visual Information Processing* (Academic Press, New York).

CLEMENT, J. 1982, Students' preconceptions in introductory mechanics. *American Journal of Physics*, Vol. 50, pp. 66–71.

MALONEY, D. P. 1984, Rule-governed approaches to physics. Newton's third law. *Physics Education*, Vol. 19, pp. 37–42.

MCCLELLAND, J. A. G. 1984, Alternative frameworks: interpretation of evidence. *European Journal of Science Education*, Vol. 6, pp. 1–6.

PAPERT, S. 1980, *Mindstorms* (Basic Books, New York).

POSNER, G. J., STRIKE, K. A., HEWSON, P. W. and GERTZOG, W. A. 1982, Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education*, Vol. 66, pp. 211–227.

TERRY, C., JONES, G., and HURFORD, W. 1985, Children's conceptual understanding of forces and equilibrium. *Physics Education*, Vol. 20, pp. 162.

VIENNOT, L. 1979, Spontaneous reasoning in elementary dynamics. *European Journal of Science Education*, Vol. 1, pp. 205–211.

WATTS, D. A. and ZYLBERSZTAJN, A. 1981, A survey of some children's ideas about force. *Physics Education*, Vol. 16, pp. 360–365.

WARREN, J. W. 1979, *Understanding Force* (John Murray, London).