Helping Students Understand Physics

An example of Newton's Third Law of Motion

Suzanne Gatt

This article outlines the factors which may make Physics a difficult and demanding subject for Maltese secondary students. The constructivist approach currently adopted by educators world-wide is described and a scheme, developed and tried out to help Maltese Junior Lyceum students understand Newton's Third Law of Motion, is described. The use of cognitive conflict, scaffolding and the social construction of knowledge in this scheme are illustrated through the activities designed. Finally, the students' reactions to this approach to teaching, and to the particular activities adopted are included.

"Physics is considered to be one of the most difficult and demanding subjects at secondary level"

SUZANNE GATT B.Ed (Hons.), M.A. (Sci. Educ.) Lond., has taught science and physics for a number of years. Ms. Gatt has an M.A. from King's College and is presently reading for a Ph.D in Science Education. She is an assistant lecturer in primary science at the Faculty of Education.

Physics is considered to be one of the most difficult and demanding subjects at secondary level. This is reflected by the limited annual pass rates of 55 to 60% at SEC level.

A variety of factors are considered to contribute to the image attributed to Physics. Fear of the subject, the mathematical and conceptual demand, and the overcrowded syllabus are among the main causes often identified.

· **Fear of the subject:** Many students experience anxiety about learning Physics before formally studying it at school. This feeling is usually passed on from year to year as students are made to believe that Physics is only for the 'brainy' students who are usually top of the class. In addition, Physics tends to be considered as a boys' subject, putting girls off it.

· **Mathematical Demand:** Physics is full of mathematical formulae. Students are faced both with the difficulty of manipulating numerical examples and with translating relationships from equations to real physical situations. Whoever is weak in mathematics will, therefore, also tend to be weak in Physics.

· **Conceptual Demand:** Physics involves many abstract and complex concepts. Mental models representing and explaining physical phenomena require a high level of thinking which many secondary students would have not reached by that age (Shayer & Adey, 1981).

· **Long Syllabus:** Teachers are often faced with covering large chunks of knowledge in the limited time available. In order to meet syllabus demands, they often resort to more traditional methods of rote learning and dictating notes, often cutting back on practical work and more meaningful learning experiences. Students will thus be bombarded with too much. Since many of the concepts in Physics are closely linked, if a part is not well understood, problems will be encountered later on.

Effective learning is considered to take place when a constructivist approach to teaching is adopted. It is by now widely accepted that little understanding, if any, occurs when passive methodologies like reading from text books and dictating notes are used. Constructivism considers learning to involve the personal construction of meanings about natural phenomena through the interaction with physical events in everyday life (Driver *et al.*, 1994). As Driver and Bell (1986) write, the constructivist view involves the following aspects:

· **Learning outcomes depend, not only on the learning environment, but also on the knowledge of the learner.** Extensive bibliographies (Duit, 1993) reporting children's alternative ideas in science have been documented in all aspects of science and particularly in Newton's Laws of Motion. No teachers can therefore assume that students do not have any idea about areas in Physics before formally studying them at school.

· **Learning involves the construction of meanings.** Students learn when they try to generate links between their existing knowledge and ideas, and those introduced during science lessons. Teaching must then be designed with children's alternative ideas in mind.

· **The construction of Meaning is a continuous and active process.** Learning involves hypothesising, testing and possibly changing ideas as new phenomena and new ideas are encountered. Thinking is continually evolving and adapting during the whole learning process.

· **Meanings, once constructed, are evaluated and can be accepted or rejected.** It is not enough for students to understand ideas and theories in science. They also need to accept that the model does actually reflect everyday situations and are ready to use it as part of their knowledge.

· **Learners have the final responsibility for learning.** Learning will only take place if students direct their attention to the learning task. The teacher should try and motivate students and to avoid short-circuiting reasoning through closed-ended questions often requiring one single direct answer.

· **Constructed meanings have similar patterns.** This occurs since students also share similar experiences of the physical world and use a common language to describe them.

A practical example

The topic 'motion' is one of the difficult areas in Physics. Students tend to attach an affective aspect to forces (Watts,1983), or else consider them to have to do with living things (Osborne,1985). Students also have difficulty in identifying a force's point of action (Terry, Jones & Hurford, 1985). Force is often taken to imply motion (Osborne,1985: Viennot, 1979) and that the greater the force the greater the velocity (Driver *et al.*, 1994).

With these problems in mind and taking a constructivist approach to teaching, a scheme for helping students understand Newton's Third law was developed. The scheme was then tried out with fourth form students attending a local Junior Lyceum girls' school.

Concepts included in Newton's Third Law

This law talks about the nature and occurrence of forces and is commonly stated as ***"every action has an equal and opposite reaction"*** (*Nelkon* & Parker, 1992). In other words, when one object A exerts a force on another object B, this object (B), will in turn, and concurrently, exert a force, equal in magnitude but opposite in direction, on object A.

Let us now consider the commonly quoted example of a block resting on a table. Two sets of Newton's pairs of forces can be identified. The first pair includes the force of the block on the table which is equal and opposite to that exerted by the table on the block. The second pair includes the force of gravity of the earth pulling down on the block (the weight) acting at the centre of gravity of the block, and the force of gravity exerted by the block on the earth, acting from the centre of the earth (figure 1).

Although all four forces identified are equal in magnitude, care must be taken in identifying which force is paired to which. As has been illustrated, the weight of the block and the reaction of the

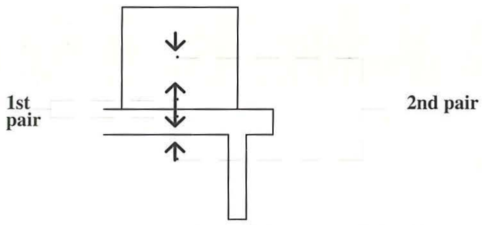

Fig. 1 Forces acting in the case of a book placed on a table (Johnson, 1983, p.109)

table, although equal and opposite, do not form a Newton's third law pair.

Newton's third law highlights a number of properties of forces. Brown (1989) lists these implications as:

· **A body cannot experience a force on its own.** As already stated forces occur in pairs, always equal and acting in opposite directions.

· **Forces arise due to the action of two bodies, when either in contact or at a distance.** So, a player kicking a ball exerts a force on the ball during contact. At the same time the ball exerts the same force, opposite in direction, on the player's foot. Similarly, two objects, a distance apart, also experience a force, known as gravitational force, on each other. Therefore the moon exerts an equal and opposite attractive force on the earth as that which the earth exerts on the moon.

· **The force exerted by the interacting bodies has the same magnitude at all moments during the time of interaction.** For example, the rope between two teams playing tug of war will always experience two equal and opposite forces, even if one team is winning.

· **No force precedes the other, even if one body may appear to be more active than the other,** as for example in the case of a moving billiard ball hitting another stationary ball. At all times during impact, both billiard balls are experiencing the same magnitude of forces.

The Teaching Scheme

The following section describes how a teaching scheme aiming at helping students understand the properties of forces, has been developed. The properties of forces just outlined are not easily accessible to students due to their elusive and abstract nature. Students, therefore, need to be provided with a number of situations where they are given the opportunity to explore their ideas about forces, leading to the construction of knowledge.

The activities designed and about to be described include particular characteristics which promote the construction of knowledge. These include cognitive conflict, scaffolding and the social construction of knowledge.

· **Cognitive Conflict** refers to situations where the predicted outcome of an experiment differs from what actually happens. It also occurs when students hold two or more different ideas about a single situation. Cognitive conflict is powerful in getting students involved in the learning activity and motivated in understanding the concepts and reasoning involved.

· **Scaffolding** Encountering concepts once is not enough to enable students to apply them to a variety of situations. Students, therefore, need to be given guidance in using the newly learnt understanding. Scaffolding refers to the amount of guidance given, and which is gradually reduced until students are capable of tackling the activities on their own. Thorpe & Gallimore (1988) and Hobsbaum *et al.* (1996) argue that scaffolding includes various stages. At first, the performance is assisted by an adult. The cognitive conflict forms part of this stage. The student then needs to attempt the activity unassisted. Mediation is provided only when necessary until performance is 'automised and fossilised' (Hobsbaum *et al.*, 1996,p.29)

· **Social Construction of Knowledge** Students should be given the time and opportunity to compare and contrast ideas with those of their peers. Social construction can therefore be achieved through talk and discussion, often in groups, of the concepts being learnt.

The Activities

Understanding Newton's Third Law was divided into three main steps, involving:

1. understanding that forces occur in pairs,
2. understanding that forces are equal in magnitude and act in opposite directions
3. being able to identify the forces present in a variety of situations.

Introducing the idea that forces occur in pairs

Students were divided into groups of four to five students, and given a settee spring together with a 2kg weight. They were first asked to find ways of making the spring shorter and longer, to notice what they had to do to achieve this, and to explain their observations in terms of forces. They were then requested to place the 2kg mass on top of the spring and to try and identify what forces they believed were present. The activity led students to appreciate that forces tend to occur in pairs, opposite to each other.

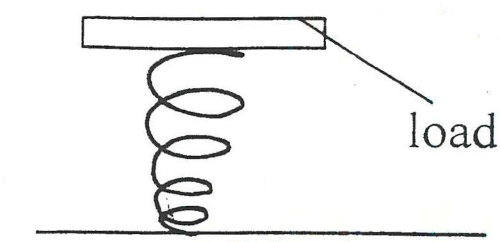

Fig. 2

Forces being equal in magnitude and opposite in direction

The magnitude of the forces was studied through an activity involving the use of spring balances. Students were asked to hook two spring balances to each other and to be held by a student at each end. They were then asked to predict what the two balances would read when (i) both students pulled at either end and (ii) below.

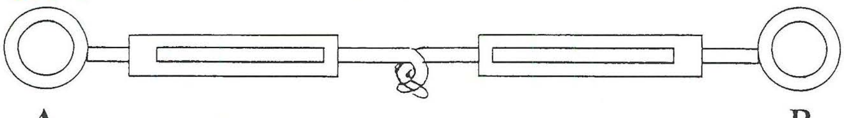

Fig. 3

"The teacher is no longer there to dish out knowledge, but to encourage students to struggle with their own reasoning"

one student pulled while the other kept her hand still. Having put down their predictions, the students then tried out the examples and noted what the actual readings obtained were.

The objective of this activity was to promote cognitive conflict. Many of the students predicted that the balances would read the same values in the first situation, but different in the second, expecting the one who was pulling to be exerting a larger force. The students were intrigued when the second case gave readings identical to the first one. It was easier, then, for the students to understand that the one holding her hand stationary was exerting a force just the same, and accept that paired forces are always equal in magnitude and opposite in direction at any one time.

1. Decide which are the two bodies exerting forces.
2. Check if the objects are in contact.
3. Decide on the points where the forces are acting.
4. Check that Newton's pairs act in opposite directions.
5. Do not forget to comment on the size of the forces.

Fig. 4

Identifying Paired forces in different situations

Students need time and guidance to gain scientific knowledge. Learning initiated by cognitive conflict just sets the initial momentum. Students need the necessary mediation (Vygotsky,1978) to develop the ability to deal with scientific concepts in different situations. Scaffolding was thus used by presenting students with different situations and asked to identify the paired forces present.

The situations considered involved the Earth and moon, a car on a road, a book on a table and a bowling ball hitting a skittle. A pack of five cards was provided to aid students in identifying the forces. The students read the cards in the order they were given. However, they were free to use as many as they felt to be necessary. This gave students control over the amount of scaffolding they had. The cards were designed so that they would eventually be discarded as students developed strategies to tackle the different examples.

Results

Cognitive conflict was effective in getting the students to think about the action of forces. As expected, many students predicted that the spring balances would give different readings when one of them was held stationary and the other pulled. It was only when they actually read the values that the student who was holding the spring balance stationary realised that she was exerting a force just the same.

The cards provided good scaffolding in helping students develop startegies for identifying Newton's pairs of forces and their point of action. It was observed that all the students read the whole pack when tackling the first example. The cards helped the students to direct their attention to the relevant properties of the situation and to eventually arrive at the pair of forces. The cards were also able to provide differentiation for students with different abilities. The better students used the pack of cards once. They had learnt the strategy to use straight away and so did not need to read through the cards again. On the other hand, weaker students used the cards repeatedly, decreasing the number they needed with each situation until they also discarded them. Overall, by the end of the set of activities, most students demonstrated insight of the various pairs of forces present in the situations considered.

Personal diaries used by students during the whole scheme also shed light on a number of other aspects. Most of the students stated that they enjoyed groupwork much more than the usual teacher talk. As the quote below shows, not only do students feel that the learning atmosphere is less formal, but are also aware that in such a setting, their ideas also count.

"The lesson was interesting because we worked in groups and everyone shared his idea"

Students were also aware of the effectiveness of the role of cognitive conflict. As one student wrote:

"I enjoyed this lesson as it gave us time to think about the experiment before we made it"

Having become aware of their own thinking process shows the effectiveness of the teaching approach adopted.

Conclusion

It is essential to end by emphasising the importance of the role taken by the teacher during these activities. The teacher is crucial both for providing an atmosphere where students are not afraid to express their ideas, and at promoting constructive learning during group work and whole class discussion. The teacher is no longer there to dish out knowledge, but rather, to encourage students to struggle with their own reasoning to try and make sense of physical situations.

The scheme described is just one application of constructive learning to a particular area in physics. If other similar initiatives were to be taken up in other areas of the subject, then Physics would cease to be such a difficult subject and would become accessible to more of our students.

References

Brown, D., (1989), Students' Concepts of Force: The importance of understanding Newton's Third Law, *Physics Education,* 24, 353-357.

Driver, R., Asoko, H., Leach J., Mortimer, E., Scott, P. (1994) Constructing Scientific Knowledge in the classroom, *Educational Researcher,* Vol. 23, No.7, 5-12.

Driver, RR. &Bell, B., (1986), Students' Thinking and the Learning of Science: A Constructivist View, *School Science Review,* 67 (240) 448-456.

Hobsbaum, A., Peters, S., & Sylva, A. , (1996), Scaffolding in Reading Recovery, *Oxford Review of Education,* 17-35.

Nelkon, M., & Parker, P. , (1992), *Advanced Level Physics*, 7th Edn., London: Heinmann Educational

Osborne, R. (1985) Building On Children's Intuitive ideas, in Osborne,R, & Freyberg P., *Learning in Science,* Hong Kong: Heinemann

Shayer M., & Adey, P., (1981), *Towards a Science of Science Teaching*, Oxford: Heinemann Educational.

Terry J., Jones, G. & Hurford, W., (1985), Children's Conceptual Understanding of Force and Equilibrium, *Physics Education,* 20, 162-165.

Thorpe R.G. & Gallimore, (1988) *Rousing Minds to Life: Teaching, Learning and Schooling in the social context,* Cambridge: Cambridge University Press.

Viennot, L., (1979), Spontaneous Reasoning in Elementary Dynamics, *Eur. Journal of Science Education,* Vol.1, No.2., 205-221.

Vygotsky, L., (1978) *Mind in Society,* London: Kegan Paul.

Watts, D.M., (1983), A study of School Children's Alternative Frameworks of the concept of Force, *Eur. Journal of Science Education,* Vol. 5, No.2 217-230.