TEACHERS' UNDERSTANDINGS AND PERCEPTIONS OF NEWTON'S THIRD LAW OF MOTION

by

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ABSTRACT

The purpose of the research was to investigate South African teachers' understandings of Newton's third law of motion, and their perceptions regarding the teaching of it. The treatment of the law by South African, British and American textbooks was also examined. Teachers' ideas were investigated qualitatively by interviewing sixteen teachers and teachers-in-training. Alternative ideas found by other researchers were evident in some of the interviewees, and further alternative ideas were uncovered. The research showed that the form in which a teacher stated the law correlated to their understanding of the law. Furthermore, experience in teaching the law can result in improvement in the understanding and/or teaching methods of a teacher. American textbooks contain the best presentation of the law; South African textbooks are adequate in their treatment, though containing errors. Recommendations have been made regarding teacher training, textbooks and education department policy.

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in the Univetsity of the Witwatersrand, Johannesburg. It has not been submitted for any degree or examination to any other university.

Signed ________________

DALE LESLEY TAYLOR

This _____ day of ____________ 1995.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NEWTON'S LAWS

Newton's laws of motion and gravitation can be stated in a number of ways. What follows are the preferred formulations of this researcher.

Newton's First Law of Motion (NEWTON I)

If the forces on a body are in equilibrium, it will continue in its state of rest or constant speed in a straight line.

Newton's Second Law of Motion (NEWTON II)

If there is a resultant force on a body, it will accelerate in the direction of the force. The magnitude of the acceleration is directly proportional to the magnitude of the resultant force, and inversely proportional to the mass of the body.

Newton's Third Law of Motion (NEWTON III)

When one body exerts a force on a second body, the second body exerts a force on the first body which is equal in magnitude and opposite in direction.

Newton's Law of Universal Gravitation (LUG)

Every body exerts a force on every other body. The magnitude of this force is directly proportional to the product of the masses of the two bodies, and inversely proportional to the square of the distance between their centres.

CHAPTER ONE
RESEARCH DESIGN

According to Newton's third law of motion (hereafter referred to as Newton III), if one body exerts a force on a second body, the second body exerts a force on the first which is equal in magnitude but opposite in direction. Another way in which this is commonly (though incompletely) stated is "for every action there is an equal and opposite reaction". This seems straightforward enough, yet the application of the law turns out to be rather difficult for people to understand. A common problem arises with the horse and cart example: if the cart pulls back on the horse as strongly as the horse pulls on the cart, how can the cart ever move?

Research (see chapter two) shows that even after being taught Newton's three laws of motion, students tend to employ alternative "common sense" ideas in understanding the forces acting on two such interacting bodies. This prompts one to ask whether teachers apply Newton III in understanding the forces acting on two interacting bodies, and whether they understand the problems which students have in grasping the law. One also wonders whether the textbooks which are used are accurate in their presentation of Newton III, and pre-empt difficulties sufficiently. The aim of this study is to throw some light on these areas.

1.1. RESEARCH QUESTIONS

In the South African context, Newton III is dealt with in physical science, which is an integrated study of physics and chemistry. Specifically, it is taught in Std 10, the twelfth and final year of school education. Thus this study looks at Std 10 physical science teachers and textbooks. The following questions were investigated:

1. What are **South African Std 10 physical science teachers' understandings** of the application of Newton III to interacting bodies?

2. What are their **perceptions** regarding the teaching of Newton III?

3. How does the treatment of Newton III in past and current South African school textbooks compare with that of British and American textbooks at the same level?

1.2. TEACHERS' UNDERSTANDINGS AND PERCEPTIONS

In order to answer the first two questions posed in section 1.1, the ideas of some teachers and teachers-in-training were sought. Since understanding and depth of ideas were required, a qualitative approach was adopted. Interviews were chosen as the best method of investigating ideas, since the researcher can then "access the perspective of the person being interviewed" (Patton, 1990:278). Responses can be probed for fuller meaning, and other clues such as pauses and tone are also available for interpretation. Ericsson and Simon (1980) argue that interview data compares well with numerical and written data in terms of its validity and usefulness.

1.2.1. Interviews

Since the researcher was not an experienced interviewer, a well developed interview guide (Appendix 1) was necessary. This guided the interviewer through the interview but was not rigid or exclusive. The Interviews-About-Instances method developed by Gilbert and Osborne (1980) was used to find out the extent to which the interviewees actually used Newton III in understanding particular situations. This method involves showing the interviewees cards with illustrations of "instances" (in this case, instances in which Newton III applies) and then asking them questions about the instances. Other questions were also asked, to find out more about the interviewees' understanding as well as their ideas on the teaching of Newton III in the classroom. In order to refine the interview guide and interviewing technique, some piloting of the interview was conducted.

A cassette recorder was used to capture each interview. Thereafter each tape was listened to, to recall the interview it represented, and transcribed. Transcriber reliability was checked by working together with a colleague on four of the transcripts. Kvale (1988) makes the point that interviews are living conversations, with transcripts merely the means by which interviews are evoked for analysis. Thus the tape-recordings were regarded as the data, with the transcripts seen as a means of recall.

Each transcript was annotated to enrich the meanings, and then interpreted as to the understandings and perceptions ot ˬ interviewee. The main features of each transcript were summarised. The transcripts were then considered together, to identify patterns and themes. Miles and Huberman's (1984) suggestion of using a type of matrix to do this - putting similar responses to each question together - was employed.

1.2.2. Sample

The interviewees were purposively drawn from the following populations:

- Std 10 physical science teachers in and around Johannesburg who were willing to be interviewed, and
- Teachers-in-training in their final year at the University of the Witwatersrand and at the Johannesburg College of Education who have physical science as one of their teaching subjects.

In all, nine physical science teachers, and seven teachers-in-training were interviewed. The interviews were conducted over the period August - October 1994, with each interview set up at a time and venue convenient to the interviewee.

1.3. TEXTBOOKS

To answer the third research question, ten South African physical science school textbooks, as well as textbooks from the U.K. and the U.S.A. at a similar or first year university level, were used. For each, the form of statement of Newton III was looked at, as well as the explanation and examples. Through the use of tables, similarities and differences amongst each group of textbooks, and between groups were identified. This gives an idea of the adequacy or otherwise of each textbook.

1.4. SUMMARY OF DESIGN

The research was designed to answer the three research questions (p 1) through two main branches:

- INTERVIEWS (Questions 1 and 2)

  Nine teachers and seven teachers-in-training were interviewed. Question 1 (relating to the understandings of teachers) was addressed primarily through the method of

Interviews-About-Instances, whilst question 2 (relating to the perceptions of teachers) was addressed by means of other questions. A pilot study was conducted, and the interviews were transcribed and analysed.

- TEXTBOOK ANALYSIS (Question 3)
  Ten South African Std 10 physical science textbooks, as well as some British and American Physics textbooks were analysed in terms of their presentation of Newton III.

The textbook analysis (chapter three) is presented before the interview analysis (chapter five) as this allows reference to be made to the textbooks in the discussion of the interviews. A review of relevant research is presented in chapter two. Chapter four contains details relating to the interviews: the profiles of the interviewees, and discussion of the interview structure, pilot study, and transcription. The analysis of the interviews is given in chapter five. In chapter six, the results of the analyses are drawn together, together with recommendations.

CHAPTER TWO
REVIEW OF RESEARCH

Central to Newton's third law of motion is the concept of force. It is thus useful to first consider the historical development of this concept. The next step is to review research relating to the ideas which students have about force, followed by a look at research which focuses specifically on students' ideas relating to Newton III. What will emerge is that traditional teaching methods are not very effective in conveying the concept of force or the meaning of Newton III to students, and so alternative teaching strategies need to be considered - first broad strategies concerned with teaching mechanics and then suggestions specific to Newton III. The last step is to consider research relating to science teachers and textbooks.

2.1. DEVELOPMENT OF THE CONCEPT OF FORCE

The development of scientific concepts is a complex process, in which many players make contributions, some larger than others. What follows is a very brief overview of the development of the concept of force and related concepts. More detail may be found in Franklin (1976) and Stinner (1994).

In everyday experience, it is generally necessary to exert a force if one wants to keep a body moving. This led Aristotle (4th century B.C.) to conclude that the motion of a body depends on the force exerted on it, as well as the resistance to motion provided by the medium in which it moves. His ideas can be represented in modern idiom by the equation

$$\mathbf{v} \propto \mathbf{F} / \mathbf{R}$$

where v is the velocity, **F** is the force exerted, and **R** is the resistance of the medium.

This relationship implies that motion in a vacuum is impossible (since v would be infinite if **R** were zero). Thus Philoponus (5th century A.D.) modified it to a relationship which can be represented by

$$\mathrm{v} \propto \mathrm{F} - \mathrm{R}$$

which allows for motion in a vacuum. Whereas Aristotle had explained the motion of projectiles in terms of air movement, Philoponus referred to an "impressed force" imparted by the thrower, which gradually dissipates. Similar ideas were held by Arab thinkers, such as Avempace (12th century).

Buridan (14th century) saw this impressed force or "impetus" as proportional to the mass and velocity of the body:

$$\text{Impetus} \propto mv$$

This foreshadowed the modern concept of momentum, but is different from it insofar as impetus was seen as the *cause* of the motion, whereas momentum is merely a property of a moving body. Buridan also suggested that impetus could be permanent in the absence of resistance. Galileo (1564-1642) built on this idea, but started to see impetus as an *effect* or measure of motion rather than a cause.

Galileo came close to the concept of inertia, but it was Newton (1642-1727) who realised that an object does not need a force acting on it to continue moving. He realised a body at rest is equivalent to a body moving at constant velocity - it depends on one's frame of reference. However, his realisation was not instant: he too started by thinking in terms of impetus, a quantity which he saw as transferable between bodies. He also had to work hard to unify his understanding of force in different situations. Newton's final idea of inertia is expressed in his laws of motion (p xi), which are true in all inertial (non-accelerating) frames of reference. To determine whether frames of reference are inertial, one needs to compare them to a single stationary frame of reference somewhere in the universe - this frame of reference is called "absolute space".

The research of this report is concerned with a Newtonian understanding of the world, but it is worth noting that Newton did not have the last say on forces. Einstein (1879-1955) pointed out that the situation of someone in an inertial frame of reference on earth is equivalent to that of someone in an accelerated frame of reference in space. His theory of General Relativity eliminates absolute space as well as gravitational force, by treating all frames of reference as equivalent, and seeing space as distorted around bodies with mass.

2.2. STUDENTS' IDEAS ABOUT FORCE

The first time students encounter the concept of force in science, it is defined as a push or pull acting on a body. This seems simple enough, yet it appears that a full understanding of the concept is not easily attained. Researchers have tried to ascertain what student understanding of the term is.

2.2.1. Supply of force notion

Viennot (1979) used open-ended questions to investigate French, Belgian and British school and university students' ideas about the forces on balls in free fall and on masses suspended from springs. (The report does not detail how much physics the students had studied, information which has significa[illegible] the results - this lack is found in a number of the reports reviewed in this chapter.[illegible] that the students had essentially two notions of force. The first concurs with the [illegible] of a force acting *on* a body, with an effect given by

$$F = ma$$

where m is the mass of the body and a is the acceleration which it experiences. This equation expresses Newton's second law of motion (p xi).

The second is that of a "supply of force" contained in a body, which is perceived as necessary for a body to keep on moving with a velocity v, according to the relationship

$$F = kv$$

where k is a constant. It is this latter intuitive but incorrect notion of force which researchers have focused on.

The above relationship implies that there is always a force in the direction of motion of a body. Clement (1982) found that 88 % of pre-physics American engineering students indicated an upwards force on a diagram of a tossed coin. Similarly, Mwakapenda (1994) found that 10 out of 12 South African students in the College of Science at the University of the Witwatersrand indicated a force in the direction of motion of a cannon ball travelling upwards. Van Hise (1988) found that before instruction, 79 % of an American class thought that the driving force on a car moving at constant velocity is greater than the retarding force. (After she had taught them, this figure was only reduced to 67 %, which gives an indication of the persistence of the idea.) She also reports on similar findings with Japanese high school students.

The "rules" of a "common-sense belief system" of force are spelt out by Champagne, Klopfer and Anderson (1980:1077) who investigated the ideas of American college students enrolled for a physics course, two-thirds of whom had done high school physics:

- a force applied to a body produces motion, a constant force producing a constant velocity proportional to the force;
- acceleration is due to increasing force; and
- in the absence of forces, a body is at rest or slowing down.

According to such a belief system, rest and constant velocity are not equivalent situations. Ueno and Arimoto (1993) explain that students cannot see the equivalence because they are accustomed to working with only one frame of reference: that of the earth. In everyday discourse, this is the assumed metacontext, for example, people refer to a car travelling at 60 km/h, and the frame of reference is understood to be the earth.

Champagne *et al.* (1980) remark that students' ideas are similar to those of Aristotle, though not as well developed. Halloun and Hestenes (1985) dispute this, claiming that students ideas of force are more often closer to the medieval impetus theory (described in section 2.1, p 6). They found that before instruction, 65 % of 478 American college physics students held impetus-type ideas, whilst only 18 % held ideas best described as Aristotelian, with the remaining 17 % holding Newtonian ideas. But they also note that there were inconsistencies in the students' ideas - students' ideas lack the coherence of well developed theories.

2.2.2. Confusion between concepts

There is also a measure of confusion between the concept of force and other related concepts. Watts and Gilbert (1983) found through the Interviews-About-Instances method (described in section 1.2.1, p 2) that some British 4th - 6th form students used the concept interchangeably with that of energy. Halloun and Hestenes note that "students are prone to use the term "force" for a variety of different concepts" (1985:1059). Watts (1983), who interviewed 12 British schoolchildren (aged 11 - 18 years), gives some of these: velocity, momentum, energy and pressure, as well as unscientific concepts. Jordaan reports on confusion amongst South African Std 10 students of the concepts of force, acceleration and velocity, with students making statements such as "force of gravity, g=10 m/s^2 = air friction" (1993a:86).

This confusion is not surprising: Hellingman (1989) points out that Newton himself had difficulties with the concept of force, and spoke at one time of inertia as an innate force of matter which is only exerted when another force acts.

2.2.3. Inanimate objects

Another difficulty which has been identified is that of appreciating that inanimate objects can exert force. Minstrell (1982b) found that about half of a pre-physics American class saw no reason for a table to exert an upwards force on an object lying on it: they saw the table as simply "in the way". Terry, Jones and Hurford (1985) report similar results with British students who had not yet been taught Newton's first law of motion. They found in discussion that the students could not see how an inanimate object *could* exert a force.

2.3. NEWTON III

The above studies have focused on students' understanding of the effect of forces acting *on* a body. This is the concept of force embodied in Newton's first and second laws of motion (Newton I and Newton II) which deal respectively with forces in equilibrium, and forces not in equilibrium (p xi). Terry and Jones (1986) and Brown (1989) note that in fact most investigations have tended to focus on Newton I and Newton II. However, Newton III broadens the picture to include the forces exerted by bodies - it draws attention to the fact that forces are the result of interactions between two bodies, with both bodies experiencing an interaction equally.

In studies which have focused on Newton III two wrong ideas come through strongly: an action-reaction (i.e. Newton III) pair of forces can cancel, and bigger, faster bodies are more "forceful", so can exert greater forces. Each of these ideas will be looked at in turn. After that, some alternative ideas published by McClelland will be discussed.

2.3.1. Action and reaction can cancel

Viennot (1979) found that students who had been taught Newton III accepted that for bodies at rest, the action force equals the reaction force. However, for moving bodies, they believed that the action exceeds the reaction, or *vice versa*, such that the "resultant force" is in the direction of motion. Similarly Jordaan (1993b) found, using a multiple choice test, that 46 % of 259 South African students who had been taught Newton's laws of motion believed that Newton III only applies to bodies in equilibrium.

Part of the problem seems to be that students do not appreciate that each force is exerted *on* one object *by* another, and that only the forces exerted *on* an object affect its motion. Ueno, Arimoto and Fujita (1990) describe this in terms of each force involving an agent (which exerts the force) and a patient (which experiences the force). When students study Newton II, they focus on one patient with a number of agents. Ueno *et al.* claim that problems arise with Newton III because students continue to think in terms of only one patient, and furthermore cannot see how a patient can also be an agent.

Terry and Jones (1986) found that most of a sample of 39 British students who had recently done "O" level physics did not appreciate that the forces described by Newton III act on two different bodies. Instead, they tended to identify an equal and opposite pair of forces acting on a single object as an action-reaction pair. So, when asked to give the reaction force to the weight of a person, the students mostly gave forces such as that of the floor on the person. For the reaction force to the weight of a falling stone, they gave air resistance. Terry *et al.* (1985) note that having been introduced to Newton III many students simply invoke it as a reason for static equilibrium.

Similarly Jordaan (1993b) found that 37 % of his sample (described above) gave the two forces on a book on a table as an action-reaction pair, and Helm (1978) found in a multiple choice test that only 53 % of 460 South African students recognised that these are not an action-reaction pair. Talisayon (1992) reports on research conducted amongst school students and university students in seven Asian countries. She notes similar confusion about action-reaction pairs in all of the seven countries.

Marais and Jordaan (1991) used the Interview-About-Instances method (described in section 1.2.1, p 2) with 117 South African Technicon students, most of whom had studied Newton's laws at school. They found that the students tended to not mention the reaction forces when asked to identify the forces acting in situations. Moolla (1989) reports on similar results with South African school students.

Nor are such problems limited to students. Hellingman claims that:

> " not only students but also *professional physicists to quite a large extent do not have a full understanding of the concept of force*" (1992:112)

He supports this by quoting from an article in an electronics periodical, where the author asserts that action and reaction balance.

Gordon, in a book intended as a university student resource (The New Science of Strong Materials), uses Newton III incorrectly. He uses it to explain why one does not fall through the floor, implying that the push exerted by a person on the floor is *cancelled* by the push which the floor exerts on the person. He goes on to say (italics added):

> "Again, the wind blowing where it listeth, pushes on my chimney pots, but the chimney pots, bless them, push back at the wind just as hard, *and that is why they don't fall off.*" (1968:27)

This is blatantly incorrect; the reason that the chimney pots remain stationary is because the force of the chimney *on* them opposes the force of the wind *on* them. Forces exerted *by* the chimney pots on the "wind" have no effect on their equilibrium.

2.3.2. Bigger and faster bodies exert greater forces

Brown (1989) reports that 78 American final year school students who had taken physics answered Newton III multiple choice questions correctly only 44 % of the time. He concluded that they tended to see the force exerted by a body as a property of that body rather than as an interaction. Thus a moving body "has more force" than a stationary one, as does a heavy body compared to a light one. Brown found that 85 % of the wrong answers given reflected such a "forcefulness" concept. Note that this idea is different from the "supply of force" idea identified by Viennot (section 2.2.1, p 7): the "supply of force" idea is invoked to explain why a particular body continues to move, whereas the "forcefulness" idea is used to determine the size of the force which a particular body will exert on *other* bodies.

Maloney (1984) investigated the reasoning patterns or rules which American college students (80 % of whom had done physics at high school) used to determine the relative magnitudes of the forces exerted by an interacting pair of bodies. He investigated the rules used by the students in understanding all permutations of two blocks of equal/unequal mass either stationary or being pushed/pulled at constant velocity/acceleration. Of the 68 students who had done college physics, only 6 used the "all equal" rule (i.e. the forces are equal regardless of the bodies' motion). None of the 44 students who had not yet done physics at college was able to answer correctly. Overall, 35 % used mass as the main determining feature (i.e. a bigger mass exerts a bigger force) whilst 28 % saw the block which "caused" the motion as exerting a greater force than the one opposing it.

Interestingly, 35 % of the students applied Newton III at rest only, whilst 17 % applied it only to situations of no acceleration. This indicates that some of the students had absorbed the content of Newton I (ie. that rest and constant velocity are equivalent situations), but had failed to make the distinction between the forces exerted on a body and the forces exerted by a body.

A similar investigation which looked also at blocks on slopes and in water was performed by Boyle and Maloney (1991). Not one of a group of 48 American pre-physics college students (irrespective of whether they had done high school physics) used the "all equal" rule in a diagnostic test. Furthermore, only 29 % of a similar group who received a thorough explanation and examples of Newton III with the test used the "all equal" rule.

This difficulty of transferring a statement of Newton III into practice is reflected in Jordaan's results (1993b). 88 % of his sample (described in section 2.3.1, p 10) claimed to understand the statement "If body A exerts a force on body B, then ...", and 93 % agreed with the statement "The action and reaction forces have the same magnitude". Yet in the same test, only 36 % thought that the gravitational forces exerted by a 20 kg body and a 40 kg body on each other were equal in magnitude.

Interestingly, most of the 39 % who felt that the 40 kg body would exert double the force of the 20 kg body justified this in terms of Newton II. In other words, instead of interpreting

$$F = ma$$

as applying to a force exerted *on* a mass m, they had interpreted it as applying to a force exerted *by* the mass. The latter interpretation ties in well with the "forcefulness" idea.

2.3.3. McClelland's ideas

In a journal article ironically entitled "Misconceptions in mechanics and how to avoid them", physics lecturer McClelland states Newton III incorrectly, using the term "resultant force" instead of "force":

> "If one body experiences a resultant force another body must experience an equal and opposite resultant force." (1985:160)

Even if the action were the only (and hence resultant) force acting on a body, there is no guarantee that the reaction is the only force acting on the second body.

It is not that McClelland uses the term "resultant force" in a non-standard way: elsewhere in the article he gives a standard definition of the term. Moreover, he states:

> "When there is no change in momentum there is no need to invoke laws II and III as each reduces to zero equals zero." (1985:160).

Certainly, when there is no resultant force (and hence no change in momentum) this is true of Newton II. But this could only be true of Newton III if Newton III were about resultant forces, which it is not.

To add to the confusion, McClelland follows this up with a discussion of the forces exerted on and by a book resting on a table, and states:

> "the gravitational force on the book is not, in general, equal and opposite to the contact force on it." (1985:160)

Provided that the table-top is horizontal, the two forces acting on the book are most certainly equal and opposite, otherwise the book would not remain at rest. Possibly what McClelland means is that the two forces are not a Newton III pair, but this fact is *always* true, not just "in general". Furthermore, these two forces are not resultant forces, and so cannot be a Newton III pair in terms of McClelland's version of Newton III.

That such an incorrect and logically incoherent formulation of Newton III can be presented by a physics lecturer is evidence of the non-trivial difficulties involved in understanding Newton III.

2.4. METHODS FOR TEACHING PHYSICS EFFECTIVELY

The problem with trying to change students' non-Newtonian ideas about mechanics is that these ideas generally "work" in people's everyday experiences. How then can teachers be most effective in changing students' ideas in line with Newton's laws? Various strategies are suggested by different authors.

2.4.1. Teacher knowledge

Minstrell (1982a) suggests that firstly and foremostly, teachers need to know what students conceptions and difficulties are. He recommends that teachers become aware of the results of research into student understandings, and also make use of Action Research in the classroom to find out their own students' ideas.

2.4.2. Models of learning

An understanding of how people learn physics is useful in teaching, and various theories have been developed. Gilbert, Watts and Osborne (1982) investigated student understandings using the Interviews-About-Instances method. They describe the various possible effects which the curriculum and "teachers' science" (presented in the classroom) can have on "children's science" (students' preconceptions), pointing out that the outcome depends on both, and is seldom "scientists' science".

Osborne (1984) describes how the "gut dynamics", which children acquire experientially, and "lay dynamics", which they acquire socially, conflict with "physicists' dynamics". He sees the difficulty as being that students do not appreciate that teachers try:

> "to provide them with an alternative conceptualization to gut dynamics using a language different from the language of lay dynamics. Rather they simply assume that the teacher is trying to help them see connections between their gut and lay dynamics." (1984:506)

Posner, Strike, Hewson and Gertzog (1982) identify the two processes which can take place when people encounter new knowledge: assimilation (using existing concepts to understand new phenomena) and accommodation (replacing existing concepts with new concepts). Other researchers call the latter process "scientific revolution" or "paradigm shift" (Champagne *et al.*, 1980) - it involves a radical conceptual change. Posner *et al.* argue that it only occurs when certain conditions are met: there needs to be a measure of dissatisfaction with existing ideas, and new ideas need to appear intelligible, plausible, and fruitful (useful).

2.4.3. Achieving conceptual change

Strategies for achieving conceptual change based on the above models have been suggested. Osborne (1984) recommends class discussions on aspects of gut and lay dynamics, and how they relate to and differ from physicists' dynamics. Watts and Gilbert (1983) suggest a three stage process: explication, where the teacher and students make explicit their interpretations of a given situation; expectation, where predictions based on the various frameworks are made; and exploration, where the predictions are tested experimentally.

As an example of how this translates into practice, Marioni (1989) gives a lesson plan for dealing with the equivalence of different inertial frames of reference. This lesson has been tested on three classes of Italian students (10 - 17 years), and was successful in effecting conceptual change. Along similar lines, Ueno and Arimoto (1993) asked students to predict what would happen in various situations, and then used computer simulations and video recordings for the exploration process. They also report conceptual change in their students.

2.4.4. Historical treatment

Stinner (1994) recommends that the story of the development of the concept of force (section 2.1, p 5) be used, along with appropriate analogies, demonstrations and thought experiments, to introduce students to Newtonian mechanics. He has tried this method with Canadian high school students and teachers, and believes that seeing the "intellectual struggle" of scientists in history aids students in their own conceptual development. Roach (1992), who has taught American students, suggests that such an approach helps students to appreciate that their ideas are not wrong so much as immature and needing to be developed.

Champagne *et al.* (1980) hold that by comparing and contrasting the Newtonian paradigm with an Aristotelian framework, students can be persuaded that Newton's ideas are more useful. They believe this should produce the necessary "scientific revolution" in students' thinking.

2.4.5. *Practical work*

Some researchers suggest experiential practical work as a route to achieving conceptual change in students. For example, Champagne *et al.* (1980) recommend the demonstration of "frictionless" situations using computer graphics, a linear air track or a "dry ice puck". However, demonstrations do not always effect the desired conceptual change, since students are likely to simply interpret what they see in terms of their existing frameworks. Halloun and Hestenes report:

> "Careful interviews of students who have just witnessed a demonstration are enough to make one dubious about the effectiveness of typical classroom physics demonstrations in altering mistaken physical beliefs." (1985:1059).

They emphasise the importance of thorough discussion to elicit and resolve conflicts.

Dana, Perkins, Ledford and St. Pierre describe an experiential method of "introducing the concept of force and Newton's three laws of motion" (1993:28) to American third graders. Students experimented at various activity stations, and then had to suggest laws. The Newton I station consisted of some of the standard inertia demonstrations, and the students concluded "Things need a force to move." In the context of the demonstrations, this actually meant that things need a force to *start* moving, but it is likely to have also been understood by the students as "things need a force to keep on moving", which would concur with their experience of the world, but in fact contradicts Newton I. So, far from introducing Newton I, Dana *et al.* were probably unwittingly helping to entrench non-Newtonian ideas.

2.4.6. *Bridging analogies*

A recent contribution to the debate on teaching mechanics is that of Clement (1993). He points out that not all the ideas with which students enter a classroom are incorrect, and suggests building on those preconceptions which concur with scientific theory - using them as "anchoring conceptions". A "target problem" is worked towards stepwise using "bridging analogies" - necessary because close analogies are easier to understand than distant ones. For example, consider the target problem of how an inanimate object such as a table exerts a force (identified as difficult for students to understand - section 2.2.3, p 9). This target problem is reached by starting with the anchoring conception of a hand pressing down on a vertical spring and experiencing a force (Figure 1, p 17). The bridging analogy used is that of a book resting on a piece of flexible board.

This method is discussion based, includes reference to scientific models, and is supported by practical experiments, such as experience with springs in the above example. Clement claims it is a form of "guided constructivism". The method was tested on American high school students in a first year physics course. For each of three lessons tested, the experimental group did significantly better than the control group who were taught using conventional methods. Along similar lines, Aquino (1994) reports success using a "modified generative teaching sequence" with 112 university physics students in the Philippines.

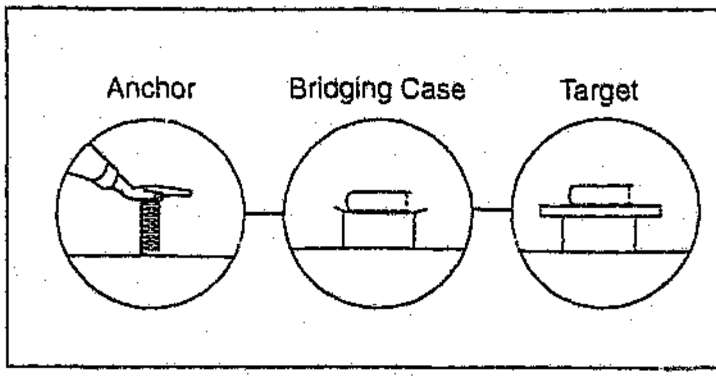

Figure 1. BRIDGING ANALOGY

Interestingly, Minstrell (1982b) put forward a very similar teaching strategy some ten years earlier. He presented a series of demonstrations to a class of American students who had not yet received instruction on forces. After each demonstration, they were required to provide force diagrams. The sequencing of the demonstrations effectively provided a series of "bridging analogies". Initially only 12 out of 27 believed that the table exerted an upwards force on a book resting on it; by the end, 25 believed the upwards force existed.

2.4.7. Preparing the way

In considering how Newtonian mechanics can be taught, it is also necessary to consider what sort of foundation is laid in preceding school years. Osborne recommends that, for the first 10 years of school, teachers should

> "help develop, challenge and extend gut and lay dynamics in such ways that it helps make better sense of the world" (1984: 507).

Such articulation of intuitive ideas provides a foundation upon which Newtonian mechanics can be built.

Both Osborne (1984) and Enderstein (1993) suggest introducing the concept of momentum much earlier. Osborne sees it as a "central aspect of gut dynamics" (1984:508) which students confuse with force. If they were given the label "momentum" to attach to this preconception,

then force could be treated as a separate concept. However, Brown (1989) feels this is not a satisfactory solution: students see the force in the direction of motion as causal, but momentum does not cause motion, it is simply a property of a body with motion.

2.5. IDEAS ON TEACHING NEWTON III

The above methods apply broadly to mechanics. There are also a number of suggestions which researchers and teachers make to assist in the teaching of Newton III. Firstly and foremostly, they suggest that more emphasis be given to Newton III in the classroom. Terry and Jones (1986) see it as important for understanding the concept of force, a sentiment which is echoed by Brown (1989). Researchers also stress the need to state the law in a helpful form, and recommend practical activities which demonstrate the law.

2.5.1. Form of statement

A translation of Newton's statement of his third law is:

> "To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts." (Cajori, 1960, quoted in Hellingman, 1989:37)

In Latin, Newton spoke of *actio* and *reactio*, but Hellingman argues that the choice of the translations "action" and "reaction" is unfortunate: the connotations are different from the Latin terms. In modern English, action is generally linked to movement, and precedes a reaction. Neither is true of a Newton III action. Furthermore, the words "action" and "reaction" do not make it sufficiently clear that what is being spoken about are forces.

Hellingman puts forward the following statement as a better alternative:

> "A force is one side of an interaction; the interaction takes place between two bodies, working equally strongly in the two opposite directions". (1992:115)

However, there is a problem with the phrase "between two bodies": it is not clear why cancellation does not occur. Jordaan suggests using the form:

> "If a body A exerts a force on body B, the body B simultaneously exerts a force of equal magnitude, but in the opposite direction on A." (1993b:1)

and Roach recommends:

> "When two bodies interact, the force of the first on the second is equal in magnitude and opposite in direction to the force of the second on the first." (1992:30)

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The common thread in all of these formulations is the mention of two bodies, with a clear indication that the two forces act on different bodies.

2.5.2. Practical demonstrations

Some researchers recommend practical demonstrations to make the content of Newton III more meaningful. Roach (1992) describes how the expulsion of gas from a balloon can be used to show the effect of the reaction force. The Israel Institute of Technology, in a unit designed to help underachievers come to grips with some of the laws of physics (Finegold, 1989), also use balloons, as well as a simple "water rocket". Coleman and Williams (1982) suggest getting two students on rollerskates to hold the ends of a rope, with one student pulling. Jordaan (1993b) recommends attaching two spring balances, and pulling them in opposite directions.

However, as mentioned (section 2.4.5, p 16), demonstrations do not always effect the desired conceptual change. Another problem is that transfer of concepts from one situation to another does not take place as easily as teachers might hope. Terry and Jones (1986) report that 90 % of their sample could answer questions about two equal mass rollerskaters correctly, since most had seen this demonstrated in the classroom. But they failed to transfer the concepts to similar situations: only 50 % could cope with the situation of skaters of unequal mass.

2.6. RESEARCH ON TEXTBOOKS AND TEACHERS' IDEAS

In considering how teachers can go about teaching Newton's laws, one needs to consider what ideas the teachers themselves hold relating to Newton's laws. It is also necessary to look at what the textbooks which are used as resources by students have to say about Newton III.

2.6.1. Teachers

The literature is somewhat sparse on research into teachers' ideas. In her conclusion, Viennot (1979) comments that teachers tend to use incorrect intuitive reasoning when they answer in a hurry, but she does not support this statement. Similarly, Jordaan reports from his own experience with teachers and teachers-in-training that "a disturbing number of them" (1993b:7) consider the two forces on a book as an action-reaction pair.

At the Sixth National Convention of Science and Mathematics Teachers (South Africa, 1975), Helm (1978) tested 65 physical science teachers' ideas, with the same multiple choice test which he had given to students (section 2.3.1, p 10). He found that 34 % thought that a bigger particle would exert a bigger force, and only 59 % recognised that the two forces on a block resting on a table are not an action-reaction pair. Similarly Hellingman (1992) asked 130 Belgian science teachers for the reaction force to the gravitational force on a bottle of wine on a table, and found that only 28 % gave correct answers.

As for research into the concept of force more broadly, Mwakapenda (1994) investigated the ideas of 7 South African senior physical science teachers at an in-service workshop. He found that 5 out of 7 indicated an upward force on a cannon ball travelling up through the air.

In all the other research reviewed in this chapter, no mention is made of teachers' ideas. The literature relating to textbooks is even thinner.

2.6.2. Textbooks

Viennot (1979) mentions that some of the general tendencies in intuitive reasoning which she found also appeared in some science textbooks, and Helm (1978) reports that some of the physics misconceptions which he identified could be found in commonly used South African textbooks, but neither gives details. Jordaan (1993b) refers to an incorrect statement of Brink and Jones (1987:21 - mentioned in section 3.5.1, p 29).

The only other reference to textbooks in the research surveyed in this chapter is that of Brown (1989) who notes that the emphasis in American textbooks tends to be on Newton's first two laws of motion, with Newton III treated only in passing. Clearly a closer look at textbooks is necessary.

2.7. OVERVIEW OF RESEARCH

The Newtonian concept of force is not intuitive, and researchers have found that students often have a persistent "supply of force" notion, similar to the medieval idea of impetus. Thus students tend to believe that a force exists in the direction of motion of a body. Researchers also note that some students experience some confusion between force and other concepts, as well as a difficulty with the idea that inanimate objects can exert force.

Newton III presents its own problems: firstly, many students believe that an action-reaction pair of forces can cancel. This reflects that they have not appreciated that the action and reaction forces act on two different bodies, or that they have not distinguished between the forces exerted *on* a body and the forces exerted *by* a body. The second main problem which students have with Newton III is they see the force which a body can exert in terms of its "forcefulness", according to which bigger and faster bodies exert greater forces. Some published articles reflect misconceptions relating to Newton III on the part of the authors.

To aid in overcoming non-Newtonian ideas, a number of strategies are suggested. Firstly, teachers need to have some idea of the misconceptions and difficulties detailed above. Some researchers have put forward models of learning, and strategies of teaching for conceptual change in terms of these models. Other researchers recommend a historical treatment, practical work, or the use of bridging analogies. Some researchers recommend that teachers lay a careful foundation in the years before Newton's laws are presented. Specific to Newton III, researchers emphasise the need to state the law in a way which makes it clear that there are two bodies involved, with the action force and the reaction force acting on different bodies. Specific practical activities relating to Newton III are suggested.

A few researchers mention that some of the misconceptions held by students are also to be found in some textbooks, and some researchers report finding that alternative ideas are held by a number of teachers. However, compared to the many studies on students, studies on textbooks and teachers' ideas on Newton III are few and far between. This study should thus help to fill a gap in the research.

CHAPTER THREE
TEXTBOOK ANALYSIS

In order to investigate the treatment of Newton III by textbooks, 23 school and university textbooks as well as some other resources were examined. This sample includes South African as well British and American books, since tertiary science textbooks in South Africa are usually drawn from these two countries. For each textbook, the actual statement of Newton III, explanation, examples, and diagrams were examined. So as to facilitate comparisons, two sets of tables were constructed. The first set (Tables 2 - 4, pp. 38 - 40) deals with the statement and explanation of Newton III, whilst the second set (Tables 5 - 7, pp. 41 - 43) deals with the examples and diagrams which are used. In this chapter, the categories in the tables are explained, and the trends in each country's textbooks are discussed. Based on this analysis, broad generalisations can be made regarding the adequacy with which Newton III is treated by the textbooks of each country.

3.1. SAMPLE

3.1.1. Textbooks

The textbooks used in this analysis are listed in Table 1 (p 23). Ten South African physical science textbooks were examined: the current English medium Std 10 textbooks, two study guides, and three older textbooks. Horn, Brink and Jones (1987) is, apart from a year plan at the front, identical to Brink and Jones (1987), and so is not included in the tables or referred to again.

Closer examination of Tables 2 and 4 (pp. 38 and 40) reveals that three South African textbooks are very similar (Gordon, Neser, Pienaar and Walters, 1969; Pienaar and Walters, 1975; and Pienaar, Walters, Schreuder and de Jager, 1987). This is because Pienaar and Walters are amongst the authors of all three textbooks. Apart from the exclusion of the horse and cart example and a worked example using momentum conservation, the text of Pienaar and Walters (1975) is almost word for word identical to that of Gordon *et al.* (1969). The

Table 1 : TEXTBOOKS USED

RSA	OLD	Prinsloo, Hattingh, Koen and Spargo	1967
		Gordon, Neser, Pienaar and Walters	1969
		Pienaar and Walters	1975
	CURRENT	Broster and James	1986
		Müller, Müller, Dreckmeyer and Dal Bianco	1986
		Brink and Jones	1987
		Horn, Brink and Jones	1987
		Pienaar, Walters, Schreuder and de Jager	1987
	STUDY GUIDES	Bowen and Roberts	1986
		Cohen	1991
UK	A-LEVEL	Nelkon and Parker	1968
		Duncan	1982
		Breithaupt	1987
	OTHER	Hall	1980
		Carrick	1982
		Keighley, McKim, Clark and Harrison	1986
		Whelan	1989
USA		Benumof	1965
		Sears, Zemansky and Young	1982
		Kane and Sternheim	1983
		Marion and Hornyak	1984
		Giancoli	1991
		Halliday, Resnick and Walker	1993

examples used in Pienaar *et al.* (1987) are simply paraphrased from Pienaar and Walters (1975), but the introductions and explanations are different - reflecting more recent educational ideas. The similarity between these three books means that some examples and statements appear very popular amongst South African texts.

The large number of textbooks available in the U.K. and U.S.A. makes it impossible to be exhaustive, so about six from each country were used. Newton III is part of the British "A" level syllabus, and three of the British textbooks are explicitly "A" level textbooks. The remaining three are pitched at about the same level. The American textbooks vary in level - some have been used at a tertiary level in South Africa.

For each country, some older textbooks were included, to find out if and how the presentation of Newton III has changed over the last three decades. In the tables, the books are ordered chronologically (by the last edition) so that any changes over time might be evident.

3.1.2. Other resources

In order to throw some light on the teaching of Newton III, the Feynman lectures (1963) and the relevant Nuffield physics teachers' guides (1966) have been looked at. In addition, one guide from each of the three countries under consideration was referred to (Saayman, 1988; Osborne and Freeman, 1989; and Arons, 1990). These books have not been analysed in the same way as the textbooks, since they serve a different purpose: they are not meant to be exhaustive, but are merely supplementary, raising certain points which are helpful to teachers. However, they will be referred to in the discussion.

3.2. POSITION IN TEXT

The first section of Tables 2 - 4 (pp. 38 - 40) is concerned with the position of Newton III in the text. The current South African core physical science syllabus places Newton III immediately after Newton I and II. This is the sequence followed by all the textbooks examined except Prinsloo *et al.* (1967), Gordon *et al.* (1969), and Pienaar and Walters (1975), which handle it after momentum (which follows Newton I and II). This reflects the order in previous South African syllabi.

The concepts of Newton III and momentum are strongly linked - many phenomena (such as the operation of space rockets) can be described either in terms of momentum conservation or in terms of Newton III. Thus the latter order of presentation is logical. It also allows for the derivation of Newton III from the expression

Impulse (Ft) = Change in momentum (Δp)

which Gordon *et al.* (1969) and hence also Pienaar and Walters (1975) use. However, Roach (1992) points out that this order can lead to confusion between the concept of force described by the third law, and the concept of momentum, thus reinforcing the incorrect view of force as a property of an object, like momentum.

3.3. FORM OF STATEMENT

3.3.1. Form A

The South African core physical science syllabus gives Newton III in the form:

> "If body A exerts a force on body B, then body B exerts an equal and opposite force on body A." (quoted in Horn, Brink and Jones, 1990, p 10)

. number of textbooks use this form, termed form A hereafter, with slight variations, such as:

> "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." (Giancoli, 1991:72)

The table distinguishes between those textbooks which use the terms body/object A and B, and those which use the terms one object and another/second object.

3.3.2. Form B

As mentioned in section 2.5.1 (p 18), Newton's statement of his third law translates as:

> "To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts." (Cajori, 1960, quoted in Hellingman, 1989:37)

In this report, this is termed form B. Two textbooks (Sears *et al.*, 1982, and Marion and Hornyak, 1984) quote this in full, but more typically it is presented incompletely, for example:

> "For every action there is an equal but opposite reaction." (Cohen, 1991:70)

3.3.3. Comparison of forms

A crucial element of Newton III is that two bodies are involved and each force is exerted on a different body. Reference to two bodies is contained in the *latter* part of form B, and "directed to contrary parts" indicates that the forces act on different bodies, although this is somewhat obscure in terms of modern English. Thus the incomplete statement of form B does not make it clear that there are two bodies involved. As mentioned in section 2.5.1 (p 18), researchers generally discourage this form - in fact, Helm refers to it as "meaningless verbiage" (1981:15). For Arons this form "has always been gibberish to the majority of students" (1990:65). Saayman (1988), and Osborne and Freeman (1989) likewise condemn it.

On the other hand, form A makes the existence of two bodies each exerting a force very clear. Thus form A is a more useful form for helping a student come to terms with the principle contained in the words, and is recommended by researchers (see p 18).

Pienaar *et al.* use an inferior variation of form A (italics added):

> "... then B *will* exert an equal but opposite force on A" (1987:15).

The insertion of "will" is probably meant to convey the fact that B *always* exerts a force, but in fact puts the second phrase into the future tense. This conveys the incorrect idea that the one force precedes the other, and so detracts from the simultaneity of the two forces. Two of the teachers' guides (Osborne and Freeman, 1989 and Saayman, 1988) also use this variation.

3.3.4. Other forms

The British authors have managed to come up with a number of other versions:

> "Action and reaction are always equal and opposite." (Nelkon and Parker, 1968:12)
>
> "Where a force acts, there will always be an equal and opposite force." (Hall, 1980:33)
>
> "When two bodies interact, they exert equal and opposite forces on one another." (Breithaupt, 1987:14)

The first two versions are similar to the incomplete version of form B, whilst the third is a more condensed version of form A.

Four textbooks (mostly American) have also given Newton III in the form of an equation, i.e.

$$\mathbf{F_{AB}} = -\mathbf{F_{BA}}.$$

3.3.5. Overview of preferred forms

Where a textbook has used two forms but indicated a preference for one, the preferred form is indicated as "1" and the other as "i". The table of British textbooks (p 39) shows a trend towards form A in more recent years. American textbooks have always tended to choose forms which indicate the two bodies. South African textbooks, however, have mostly stuck doggedly to the unhelpful incomplete version of form B. This is particularly odd, given that the syllabus gives form A. South African textbooks have also not made use of symbolic representation in the form of an equation.

3.4. DISCUSSION

Boyle and Maloney (1991) found that a written statement of Newton III supplied with a test involving Newton III type examples had no effect on the answers which students gave. Thus a mere statement of the law is insufficient to change people's ideas on forces. It needs to be followed by discussion which preempts the common misconceptions which people have. After dealing with the form of statement of Newton III, the tables identify the points raised in discussion. The third section gives the points made in the basic explanations; the fourth section considers links made to the other two laws of motion; and the fifth section looks at the use of the terms action and reaction.

3.4.1. Explanation

There are six points listed in the "Explanation" section. The first point refers to the terms "equal and opposite". These are not self-explanatory and need some explanation: the *sizes* are equal and the *directions* are opposite.

The finding that students tend to think that action and reaction forces can cancel (section 2.3.1, p 10) points to the need to communicate effectively that the forces act on two *different* bodies (point 2) and thus can NOT cancel (point 3). Pointing out that the distinction between the forces which act *on* a body and the forces which are exerted *by* that body (point 4) can aid in this - only the forces exerted *on* a body affect its motion. A corollary to Newton III is that forces always occur in pairs (point 5). But it is also worth pointing out that not all pairs of equal and opposite forces are action-reaction pairs (point 6).

3.4.2. Links to Newton I and Newton II

This last point can be further emphasised by examining the difference between Newton I pairs (acting on the same body and cancelling) and Newton III pairs (which act on different bodies). Some textbooks look at a number of forces in a situation, and classify them as Newton I or Newton III pairs - this should help to pre-empt the misconception that action and reaction forces can cancel.

In putting Newton III in a broader context, it is a good idea to use Newton II to explain why the effects of two forces of the same magnitude may be vastly different. This should help overcome the "forcefulness" misconception that bigger, faster bodies exert greater forces (section 2.3.2, p 11). The fourth section of the tables thus indicates whether each textbook examines Newton III in the context of each of the other laws of motion.

3.4.3. Action and reaction forces

Nearly all the American and South African textbooks used either the terms "action" and "reaction" or the terms "action force" and "reaction force". But, as noted (section 2.5.1, p 18), Hellingman (1989) points out that these can be misleading. They can also lead to fruitless "chicken and egg" debates as to which is the action force. Thus it is necessary to point out that the terms are mostly interchangeable - this helps to emphasise the simultaneity of the two.

The fifth section of the tables indicates whether each book used the terms action and reaction, and whether each book explained that the terms are in fact interchangeable. If the terms have been used, then their equivalence should also be noted. This is true of most of the American textbooks which used the terms. However nearly all of the South African textbooks used the terms, and yet not one explained that they are equivalent. Most of the British textbooks did not use the terms, so did not need to mention their equivalence.

3.4.4. Overview of discussion

The older British texts contain no discussion of Newton III but the more recent texts do include brief explanations. The American texts contrast strongly with this: three included all but two of the above-mentioned ten points. The South African explanations show a lot of similarity to each other; generally sound though students are likely to come away with the impression that all equal and opposite pairs are Newton III pairs.

3.5. INCORRECT AND MISLEADING STATEMENTS

A number of the textbooks included incorrect and/or misleading statements in their discussion of Newton III. These are quoted and discussed in this section.

3.5.1. Action and reaction can cancel

Some textbooks make statements which are likely to reinforce the misconception that action and reaction forces can cancel (section 2.3.1, p 10). Carrick, in describing a hovering bird, states:

> "The bird causes a downward force on the air, with the result that the air causes an upward force on the bird. This enables the bird to stay stationary in the sky." (1982:53).

And Broster and James explain the reaction force on a book resting on a table:

> "The table exerts an upward reaction force on the book. If it did not, the book would fall down!" (1986:16)

While both these statements are in fact correct, they are misleading in that they present the reaction force as the reason for the equilibrium of the body under discussion. Since no mention is made of the gravitational force on the body, this gives the incorrect impression that the reaction force balances the action force, instead of the gravitational force. The implication is that the action and reaction forces cancel, and Newton III leads to equilibrium.

Certain other textbooks perpetuate the misconception that action and reaction forces can cancel with statements which are incorrect. The weight of an object is the gravitational force which the earth exerts *on* the object, but these books present the weight of an object as a force which is exerted *by* the object:

> "The weight of the book is the downward force on the table" (Bowen and Roberts, 1986:76; Brink and Jones, 1987:21, make a similar statement)

The force which the book exerts on the table occurs *as a result of* the weight of the book but the weight of the book and the force which it exerts on the table are in fact two distinct forces acting on two distinct bodies. They are also two different types of forces: one is a gravitational attraction between two masses, whilst the other is a force of repulsion between two bodies in contact. So these authors are in error in treating the *gravitational* force on the *book* (weight) and the *contact* force on the *table* as one and the same force.

Breithaupt also confuses which body the weight of a person acts on:

> "When you sit on a chair, your weight pushes on the chair." (Breithaupt, 1987:14)

In fact "your weight" is a pull on a person, not a push on a chair. Furthermore, this quote describes a *force* (weight) exerting a force, which is nonsense: *bodies* exert forces.

3.5.2. Careless language

Having learnt that forces are exerted *on* bodies, students must be confused when confronted with the following statements (italics added):

> "An action and a reaction force are *between* bodies and they do not cancel each other out." (Broster and James, 1986:17)
>
> "to overcome the forces of friction *in* the car." (Brink and Jones, 1987:22)
>
> "Only forces acting on *the same point* can balance." (Müller *et al.*, 1986:20)

The first statement could be interpreted as meaning that action and reaction forces are a different type of force which acts *between* bodies instead of *on* them. The second is blatantly incorrect (what is meant are the forces of friction *on* the car) as is the third (two forces can act at different points on an object, and yet balance).

3.5.3. Balanced and unbalanced forces

The concept of balanced forces caused further problems for some authors:

> "the action-reaction pair must be part of an isolated system to produce motion." (Pienaar and Walters, 1975:109; the IMSTUS teachers' guide (Saayman) contains a similar statement, 1988:15)

> "The action and reaction forces act on different objects, therefore they are both unbalanced forces." (Cohen, 1991:70)

Clearly both statements are over-generalisations - in every situation all the forces acting on each body need to be considered to determine its motion (Newton I and II).

The content of Newton I seems to have passed by the following authors:

> "If the lift is at rest or travelling with uniform velocity, then the only force acting is the weight." (Bowen and Roberts, 1986:77)

If a body is at rest or travelling with uniform velocity, then the forces on it must be in equilibrium (Newton 1), which is impossible if only one force is acting.

In discussing the concept of resultant force, Arons notes that

> "There is a strong tendency among students to think of some of the individual forces as having disappeared, or having been somehow obliterated, in the superposition, especially when some of the forces oppose each other and are "overcome" in the final effect." (1990:63)

Broster and James help to perpetuate this idea - in talking about the effect of a force of friction of 400 N acting on a car which is being pushed by a man, they conclude incorrectly:

> "Therefore the force exerted by the man is reduced by 400 N." (1986:17)

Rather it is the *resultant* force which is reduced.

3.5.4. Universality

In all the forms used in the textbooks it is implicit that Newton III is universal. In fact, Newton III does not apply exactly at every instant to forces which act over large distances, since information about a change in one of the bodies cannot be communicated to the other faster than the speed of light. So Newton III applies exactly to all contact forces, and nearly exactly to all non-contact forces provided that the distances are not too great.

Only two texts deal with the question of universality explicitly. Duncan points out:

> "more exact laws are required for certain extreme cases" (1982:142).

And Sears *et al.* (1982:23) note that it does not apply to forces between moving electrical charges.

But some textbooks make statements which imply that Newton III does not apply in all cases. Carrick states:

> "This situation with two opposite forces is very common." (1982:53),

which implies that, while common, it is not always the case.

Brink and Jones describe a boy exerting a force of 10 N on a second boy, and tell us that the second boy will exert a force of 10 N too:

> "but only if the second boy is capable of exerting a force of 10 N." (1987:22).

This is nonsense: the first boy will only succeed in exerting a 10 N force in the first place if the second boy is capable of exerting a 10 N force - the maximum value for both is limited by the weaker body.

Gordon *et al.* make the point that Newton III "is not concerned directly with motion" (1969:94). This is valid, but this statement may help to convey the incorrect impression that Newton III only applies in static situations. The other two textbooks in the Pienaar and Walters trio (Pienaar and Walters, 1975, and Pienaar *et al.* 1987) also make this point.

3.5.5. Summary of incorrect statements

All but two of the nine South African textbooks contain at least one incorrect statement in the section on Newton III. In contrast, only one of the British textbooks (Breithaupt, 1987) contains an error, and not one of the American textbooks contains an error. Misleading statements are found in one South African textbook and two British textbooks. It would seem that the South African textbooks are subject to less scrutiny before publication.

Possibly some of the seven American and British textbooks which are not first editions contained errors in earlier editions. However it is worth noting that all but one of the first edition overseas textbooks are written by only one author, compared to the two or four authors of most of the South African texts. So the errors in South African textbooks have generally passed by more than one author without being picked up.

3.6. POINTS NOT INCLUDED IN THE TABLES

3.6.1. Treatment of strings

Helm's multiple choice test (see p 10) included the following question:

> "A man pulls sideways on a string which is attached to the leg of a table. The reaction to the force exerted by the man is exerted by
> (a) the string
> (b) the table
> (c) the earth
> (d) the floor" (1978:289).

Only 15 % of 460 students chose the string - 56 % opted for the table. Ivowi (1984) obtained similar results with 257 Nigerian students (string: 28 %; table: 48 %). Helm saw this as a Newton III misconception and mentioned that it was present in some South African textbooks. It is thus interesting to consider how the textbooks under consideration deal with strings. Since not all the texts deal with this under Newton III, this information has not been included in the tables, but will be discussed here.

Some texts treat the string (or rope or towbar) as a body in its own right, examining the forces which are exerted on it (Gordon *et al.*, 1969; Carrick, 1982; Duncan, 1982; and Sears *et al.*, 1982). But others treat the string rather as a transmitter of force. Gordon *et al.* having examined the forces on a rope, go on to say:

> "A rope transmits a pull without change from one end to the other." (1969:95).

More often, however, the idea of a string as merely a transmitter of force is not stated explicitly but simply assumed (Bowen and Roberts, 1986; Hall, 1980; and Breithaupt, 1987). For example, the Nuffield teachers' guide (1966) suggests asking a student to pull on one end of a metre stick whilst the teacher pulls on the other end (year III:259). The forces on the metre stick are not mentioned; it is simply treated as a transmitter of force.

Strictly speaking, Helm is correct in regarding a string (or equivalent) as a body. But treating a string as a transmitter of force is a useful mathematical construct which works because the string's mass is negligible. Since this is commonly done, perhaps Helm is being pedantic in calling it a misconception. However, if textbooks treat strings as transmitters of forces for the purposes of solving problems, then perhaps they should deal with this concept explicitly instead of assuming it implicitly.

3.6.2. Inanimate objects

Arons makes the point that

> "many students have the preconception that forces can only be exerted by living beings, and they balk at the idea of a table, a floor, a block exerting a force on anything." (1990:64)

This concurs with the finding of Terry *et al.* (1985) with pre-physics students (see section 2.2.3, p 9). Arons points out that this problem is not trivial, and suggests that teachers explain that even an object which appears rigid is deformed to some extent when a force is exerted on it. Gordon (1968) explains this in terms of the bonds behaving as tiny electrical springs. Giancoli (1991) is the only textbook author who tackles this concept, using a description similar to Arons.

3.7. EXAMPLES USED

The second set of tables (Tables 5 - 7, pp. 41 - 43) deals with the examples used. All but four of the textbooks examined limit their examples to contact examples. This tacitly communicates the assumption that Newton III only applies to contact forces, and hence places limitations on its universality. Of the four which widen the horizon, only one (Broster and James, 1986) mentions electrical and magnetic forces: the other three only consider gravitational forces. Arons (1990) sees non-contact examples as valuable: it is easier for students to discern the two separate actions involved.

3.7.1. Contact forces

As for contact forces, all specific examples which appear in more than one textbook have been listed, as it is interesting to see how some examples seem to be favourites for explaining Newton III. Examples which appear in only one textbook simply fit into the "other" category.

To give students as broad a feel for Newton III as possible, it seems to make sense to include both push and pull examples, as well as both static and dynamic examples. According to this, a good textbook should have at least one example in each of the four main contact categories. The South African textbooks (Table 5) are the most generous with examples, but these tend to cluster in the "dynamic-push" section. The examples which are given in the core syllabus, i.e. walking, pressing against a wall, and a rocket, are frequently used.

3.7.2. Horse and cart

The South African core physical science syllabus classifies the above examples as "simple" and states that one should:

> "Exclude more difficult cases e.g. a horse pulling a cart". (quoted in Horn *et al.*, 1990:16)

This seems unfortunate: the horse and cart example is particularly illuminating, since it shows clearly that the action-reaction pair of forces do not cancel each other. Viennot remarks that too often only static cases are dealt with, and recommends that "the most confusing case" (1979:216) should be done: a man pushing on a car. This is analogous to the horse and cart situation. The horse and cart example is also useful for emphasising the need to look at all the forces acting *on* a body in order to determine its motion. If someone cannot explain why the cart accelerates, they have not fully understood Newton II and III.

Overall, the horse and cart example is not a popular example - only three textbooks use it. Gordon *et al.* (1969) are the only South African authors to include it, and in fact they make it unnecessarily difficult by including a rope between the horse and cart. The IMSTUS guide (Saayman, 1988) suggests keeping one's fingers crossed that the horse and cart example does not come up in class discussion, but provides a not altogether helpful diagram to use if it does.

3.7.3. Obscure examples

The British textbooks are conspicuously sparse on examples, and, furthermore, have sometimes chosen singularly unhelpful ones. Carrick mentions a hovering bird (see section 3.5.1, p 28) and a jetfoil. Both involve aerofoils, the mechanism of which is not explained. The motion of a bird's wings is in fact extremely complicated, and a student could quite logically argue that as much as a bird exerts a downward force when its wings move down, it also exerts an upward force when its wings move up.

3.8. DIAGRAMS

Diagrams have tremendous potential in helping students to understand the application of Newton III to specific examples. Thus the diagrams used have also been dealt with, in the last section of Tables 5 - 7. Some textbooks include unlabelled, unarrowed sketches and photographs - these have been included in the count.

In diagrams which include arrows to represent each force acting, it is sometimes difficult to make out just which body each force acts on. Arons (1990) and Roach (1992) suggest overcoming this problem by showing each body separately. The tables thus distinguish between diagrams where the bodies are shown together, and diagrams where the bodies are shown separately. Most of the diagrams used in the textbooks fall into the former category.

Although it is conventional to use an arrow to represent each force, there is no convention regarding just where the arrow should be drawn. Physically, a contact force acts over an area on the surface of a body, and is distributed to all the parts of the body by many internal action-reaction pairs of forces. So it is logical to draw contact forces at the centre point of contact, and this is given as the first option under "Forces" on the tables.

Non-contact gravitational/electrostatic forces act on every bit of mass/charge but can be treated mathematically as if they act at the centre of mass/charge. Contact forces which are directed towards the centre of mass can be treated in the same way. So it is also logical to draw forces at the centre of mass of an object, i.e. with the tail of the arrow at the centre of mass. This is the second "Forces" option in the tables.

However, it seems there are two ways of drawing contact push forces:

$$\underset{F_{A\,on\,B}\;F_{B\,on\,A}}{A\rightarrow\vdots\leftarrow B} \quad \text{or} \quad \underset{F_{B\,on\,A}\;F_{A\,on\,B}}{A\leftarrow\vdots\rightarrow B}$$

The first option emphasises *by* which body each force is exerted, whilst the second emphasises *on* which body each force is exerted. However, the second option looks the same as a pair of pull forces drawn at the point of contact. The distinction between these two methods is not made in the tables.

The third "Forces" option in the table refers to a method used by Gordon *et al.* (1969). They draw both the action and the reaction forces at the centre of mass of a rocket, and of a jet aeroplane. Thus both forces appear to act on the rocket or aeroplane. This serves to perpetuate the confusion between Newton I and Newton III pairs of forces. Since Pienaar and Walters (1975) and Pienaar *et al.* (1987) have copied diagrams as well as text, these two diagrams appear in their textbooks too. The IMSTUS guide (Saayman, 1988) also features the rocket diagram.

Broster and James (1986) generally show the action-reaction pairs of forces at the points of contact. However, for some unknown reason, in their diagram of a man pushing a crate, they show the Newton III pair of forces acting at the centre of mass of the man. Reference to the tables shows that such a lack of consistency of style in diagrams within a textbook is fairly common. This, coupled with the lack of clarity which arises from drawing the bodies together, means that diagrams often do not fulfil their potential in helping the reader to understand the application of Newton III. In fact, certain diagrams seem more likely to confuse than to help.

3.9. CHANGES OVER TIME

It is evident from the tables that the treatment of Newton III is more detailed in more recent books. This could reflect the growth in understanding of the difficulties which learners have with Newton III. Arons notes:

> "Once we are used to it, the idea articulated in the Third Law seems transparently simple, and teachers tend to become insensitive to the very great difficulty the majority of students encounter." (1990:64)

Certainly this seems to have been true of Feynman, whose treatment amounts to little more than the statement "action equals reaction" (1963:10-2), with no examples - which indicates that he did not see it as presenting any problems. Similarly, the Nuffield guide, while providing excellent experiential examples, fails to pre-empt misconceptions to the same extent which some later textbooks and guides do.

3.10. CONCLUSION

Over time the treatment of Newton III by textbooks has generally become more detailed, with more attempts to pre-empt misconceptions. Overall, the modern American textbooks come through as presenting the best treatment of Newton III. They generally use suitable forms, helpful discussion, and contain no errors. The British textbooks are accurate (apart from Breithaupt, 1987), though brief in their treatment and sometimes unhelpful or even obscure (notably Carrick, 1982).

The South African textbooks' treatment of Newton III is closer to the American treatment than the British treatment. The South African explanations are generally adequate although they mostly fail to pre-empt the misconception that all equal and opposite pairs of forces are Newton III pairs. However, all but one (Prinsloo *et al.*, 1967) of the South African textbooks contain at least one error in text and/or diagrams, which undermine the explanations. The South African textbooks also mostly use an inferior statement of the law (the incomplete form B).

The South African textbooks are, however, more generous than the rest with examples. Unfortunately though, these are often very similar, and do not exploit the range of variations which exists: they mostly cluster in the "dynamic-push" section. The potential of diagrams in explaining examples is not fully realised, and in fact is undermined by inconsistent or incorrect use of arrows in many textbooks.

Table 2: SOUTH AFRICAN TEXTBOOKS' TREATMENT OF NEWTON III

TEXTBOOK (See key below):			a	b	c	d	e	f	g	h	j
Position in text	After NI/ NII	Simply stated				1		1	1		
		Deduced from examples					1			1	
	After Momentum		1	1	1						
Form	A	If Body A exerts ...		i	i	1	1			1	
		If one object exerts ...						i			
	B	For every action...(complete)									
		For every action (incomplete)	1	1	1	i		1	1	1	1
	Other										
	Equation: $F_{AB} = -F_{BA}$										
Explanation		Equal and opposite explained				1	i	1		1	1
		Act on 2 different bodies		1	1	1	1	1	1	1	1
		Forces can't balance / cancel		1	1	1	1	1	1	1	
		"On" and "by" distinction									
		Forces always occur in pairs	1	1	1			1			
		Not all equal and opp. forces									
Linked to NI & NII		Diff. between NI & NIII pairs									
		NII explains different a's			1				1	1	
Action and reaction forces		Terms used in examples		1	1	1	1	1	1	1	1
		Can be interchanged									
Misleading statements							2				
Incorrect statements				1	1	2	1	1	3		1

KEY: 1 Indicates item is present
i Indicates item is stated but with less emphasis
2,3 Indicates 2 or 3 occurrences of item

a. Prinsloo, Hattingh, Koen and Spargo (1967)
b. Gordon, Neser, Pienaar and Walters (1969)
c. Pienaar and Walters (1975; 1st ed:1975)
d. Bowen and Roberts (1986)
e. Broster and James (1986)
f. Müller, Müller, Dreckmeyer and Dal Bianco (1986)
g. Brink and Jones (1987)
h. Pienaar, Walters, Schreuder and de Jager (1987)
j. Cohen (1991)

Table 3 : BRITISH TEXTBOOK'S TREATMENT OF NEWTON III

TEXTBOOK (See key below):			k	l	m	n	o	p	q
Position in text	After NI/ NII	Simply stated	1		1	1	1	1	1
		Deduced from examples		1					
	After Momentum								
Form	A	If Body A exerts ...				1	1		1
		If one object exerts ...							
	B	For every action...(complete)							
		For every action (incomplete)			1				
	Other		1	1				1	
	Equation: $F_{AB} = -F_{BA}$								1
Explanation		Equal and opposite explained						1	1
		Act on 2 different bodies				1		1	1
		Forces can't balance / cancel							
		"On" and "by" distinction							
		Forces always occur in pairs				1			
		Not all equal and opp. forces							
Linked to NI & NII		Diff. between NI & NIII pairs							
		NII explains different a's				1			
Action and reaction forces		Terms used in examples			1				
		Can be interchanged							
Misleading statements					2			1	
Incorrect statements								1	

KEY: 1 Indicates item is present
i Indicates item is stated but with less emphasis
2,3 Indicates 2 or 3 occurrences of item

k. Nelkon and Parker (1968; 1st ed:1958)
l. Hall (1980)
m. Carrick (1982)
n. Duncan (1982)
o. Keighley, McKim, Clark, Harrison (1986; 1st ed: 1982)
p. Breithaupt (1987)
q. Whelan (1989; 1st ed: 1978)

Table 4 : AMERICAN TEXTBOOKS' TREATMENT OF NEWTON III

TEXTBOOK (See key below)::			r	s	t	u	v	w
Position in text	After NI/ NII	Simply stated	1	1		1		
		Deduced from examples			1		1	1
	After Momentum							
Form	A	If Body A exerts ...						i
		If one object exerts ...			1		1	
	B	For every action...(complete)		1		1		
		For every action (incomplete)	1				i	i
	Other							
	Equation: $F_{AB} = -F_{BA}$			i		1		1
Explanation		Equal and opposite explained		1	1			1
		Act on 2 different bodies	1	1	1	1	1	1
		Forces can't balance / cancel			1			1
		"On" and "by" distinction		1	1		1	
		Forces always occur in pairs		1		1		1
		Not all equal and opp. forces		1	1			1
Linked to NI & NII		Diff. between NI & NIII pairs		1	1			
		NII explains different a's	1					1
Action and reaction forces		Terms used in examples	1	1	1	1	1	1
		Can be interchanged		1	1	1		1
Misleading statements								
Incorrect statements								

KEY 1 Indicates item is present
i Indicates item is stated but with less emphasis
2,3 Indicates 2 or 3 occurrences of item

r. Benumof (1965)
s. Sears, Zemansky and Young (1982; 1st ed: 1949)
t. Kane and Sternheim (1983; 1st ed: 1978)
u. Marion and Hornyak (1984)
v. Giancoli (1991; 1st ed: 1980)
w. Halliday, Resnick and Walker (1993; 1st ed: 1974)

Table 5 : SOUTH AFRICAN TEXTBOOK EXAMPLES ON NIII

TEXTBOOK (See key beneath table 1):				a	b	c	d	e	f	g	h	j
Contact examples	Static	Push	Book on table				1	1		1		1
			Person on wall			1	1		1			
			Hand on table	1					1			
			Other									
		Pull	Springbalances					1	1	1	1	
			Rope on block									
			Other									
	Dynamic	Push	Walking			1	1	1	1	1	1	
			Rocket		1	1	1	1	1		1	1
			Step off boat							1		
			Gun/ cannon		1	1				1	1	1
			P on car/crate					2		1	1	
			2 skaters		1	1					1	
			Jet aeroplane		1	1					1	
			Astronaut		1	1					1	
			Hammer on nail									
			P on pool wall								1	
			Other							1		
		Pull	Horse/ car/ person & cart		1							
			Other			1					1	
Non-contact examples	Gravita-tional	Static	Book on earth									
		Dynamic	Falling object									
			Planets etc					1				
	Electrostatic							1				
	Magnetic							1				
Diagrams	Objects	Shown together			3	4	1	9	4	4	5	
		Shown separated										
	Forces	Drawn at pt of contact			1	1		4	2	1	2	
		Drawn from c's of mass				1			1		1	
		From c. of m of 1 body			2	2		1			2	
		Other					1	3				

Table 6 : BRITISH TEXTBOOK EXAMPLES ON NIII

TEXTBOOK (See key beneath table 2):				k	l	m	n	o	p	q
Contact examples	Static	Push	Book on table				1			
			Person on wall							
			Hand on table							
			Other			3			1	
		Pull	Springbalances							
			Rope on block				1			
			Other			1				
	Dynamic	Push	Walking				1			
			Rocket			1				
			Step off boat					1		
			Gun/ cannon							
			P on car/crate							
			2 skaters							
			Jet aeroplane							
			Astronaut							
			Hammer on nail							
			P on pool wall							
			Other			1				
		Pull	Horse/ car/ person & cart						1	
			Other		1					
Non-contact examples	Gravita-tional	Static	Book on earth							
		Dynamic	Falling object			1				
			Planets etc							
	Electrostatic									
	Magnetic									
Diagrams	Objects	Shown together			1	7	1	1	1	
		Shown separated					1			
	Forces	Drawn at pt of contact				2	2		1	
		Drawn from c's of mass				2				
		From c. of m of 1 body								
		Other				1				

Table 7 : AMERICAN TEXTBOOK EXAMPLES ON NIII

TEXTBOOK (See key beneath table 3):				r	s	t	u	v	w
Contact examples	Static	Push	Book on table						1
			Person on wall						1
			Hand on table					1	
			Other			1			
		Pull	Springbalances						
			Rope on block		1				
			Other				1		
	Dynamic	Push	Walking	1		1		1	
			Rocket					1	
			Step off boat	1					
			Gun/ cannon						
			P on car/crate			1	1		
			2 skaters						
			Jet aeroplane						
			Astronaut						
			Hammer on nail					1	1
			P on pool wall			1			
			Other					4	
		Pull	Horse/ car/ person & cart					1	
			Other					1	
Non-contact examples	Gravita-tional	Static	Book on earth			1			1
		Dynamic	Falling object			1			
			Planets etc						1
	Electrostatic								
	Magnetic								
Diagrams	Objects	Shown together			1	3	2	7	6
		Shown separated			1	8	2		1
	Forces	Drawn at pt of contact			1	3	3	4	1
		Drawn from c's of mass				1			2
		From c. of m of 1 body							
		Other							

CHAPTER FOUR

INTERVIEWS

Details relating to the interviews of teachers and teachers-in-training are presented in this chapter. First, the interviewees themselves are looked at: their qualifications and experience relating to teaching as well as other relevant information are tabulated and discussed. Then the structure of the interviews is outlined, and the questions asked in the interviews are analysed in terms of types of questions. Thereafter the piloting of the interview is described. The last section reports on the transcription of the interviews: the decisions taken with regard to punctuation, and the means by which transcriber reliability was established. The results of the transcriber reliability analysis are presented. The analysis of the interviews follows in chapter five.

4.1. INTERVIEWEES

A summary of the profiles of the seven final year teaching students (S1 - S7) and the nine physical science teachers (T1 - T9) interviewed is contained in Table 8 (p 45). This information was obtained at the beginning of each interview. The numbering of the interviewees indicates the sequences in which they were interviewed. An explanation of the various categories in the table follows.

4.1.1. Institutions

The institutions indicated in Table 8 are those where the interviewees were working or studying when interviewed. Most of the teachers were teaching at schools in the historically white Transvaal Education Department (TED), whilst T2 was working at the University of the Witwatersrand (Wits), and T9 was teaching at a school in the historically black Department of Education and Training (DET). The students were all studying at Wits or the Johannesburg College of Education (JCE).

Table 8 : PROFILES OF INTERVIEWEES

		INSTITUTION	QUALIFICATION	PH	M/F	YEARS TEACHING	Std10 YEARS
STUDENTS	S1*	Wits	BSc HDE	I	F	Extra	0
	S2*			IA	F	0	0
	S3*			I	M	Extra	Extra
	S4*			I	M	3 yrs	1 yr
	S5	JCE	HDE	II	F	Extra	0
	S6			II	M	0	0
	S7			II	M	0	0
TEACHERS	T1*	TED School	BSc HDE	I	F	5	5
	T2*	Wits	HDE BA	II	F	>10	>5
	T3	TED School	BSc HDE	II	M	3	3
	T4	TED School	BSc HDE	I	F	>15	>10
	T5	TED School	HDE	II	M	>5	>5
	T6	TED School	BScHons HDE	I	F	>20	>20
	T7	TED School	BScHons HDE	I	F	>20	>20
	T8	TED School	BScHons HDE	I	F	>20	>20
	T9	DET School	BScHons HDE	I	F	3	1

KEY: * indicates that the interviewee was part of the pilot study.
PH indicates the number of years of tertiary physics.
Extra indicates only teaching experience is in giving extra lessons.

4.1.2. Qualifications

Some explanation of the qualifications of the interviewees may be in order. BSc HDE denotes a Bachelor of Science degree (a three year university science degree) with a Higher Diploma in Education (a one year post-graduate university diploma) or equivalent - different institutions use different names for this diploma. However, HDE placed first refers to a four year diploma from a teachers' training college (such as JCE). Additionally some interviewees had Honours degrees (one year post-graduate), and T2 had a Bachelor of Arts degree.

In the case of the students, the HDE would be attained at the end of the 1994 academic year. All students were in their final year of study, and had physical science as one of their teaching subjects. Three of the four students at Wits had done the course "Physical Science Additional Studies" in their HDE, where Newton's laws and the misconceptions associated with them had been addressed briefly.

Thus all of the interviewees were either qualified high school physical science teachers or were in the process of becoming such. Strictly speaking the HDE obtained from JCE (or any teachers' training college, rather than a university) does not qualify one to teach Std 10, where Newton III is taught. However, it is generally accepted that, given the prevailing shortage of qualified senior physical science teachers, most people with this qualification are likely to end up teaching Std 10, as can be seen with T5.

PH indicates the number of years of tertiary physics which each interviewee had studied. "IA" represents the physics auxiliary course which is offered to students planning to continue with physics. Those who studied at teachers training colleges did physics for four years, but since this is equivalent to two years of university physics, it has been indicated as such for the purposes of comparison. As can be seen, no teachers with a university physics major could be found (apart from the researcher).

4.1.3. Gender

The gender of each interviewee (Male / Female) is also noted. That more female teachers were interviewed is probably a reflection of the physical science teaching population.

4.1.4. Teaching Experience

The number of years of experience in physical science teaching is indicated for each interviewee, as well as the number of years of experience in teaching Std 10 physical science. The students were mostly inexperienced, while the teachers' experience varied - a full spectrum is thus represented. All of the students were completing the compulsory practical teaching experience at secondary schools (which excluded Std 10 teaching), but this has not been included in the table: only additional experience is shown. "Extra" denotes some form of extra lessons - private tuition or Saturday schools.

4.2. INTERVIEW STRUCTURE

The interviewer worked according to the interview guide given in Appendix 1. The exact wording and order of the questions asked were not necessarily the same as the guide, and not all of the questions were asked of every interviewee. (Patton, 1990:283).

4.2.1. Interviews-about-instances

The first section of the interview employed the Interviews-About-Instances (IAI) method. Each interviewee was shown three or four of the IAI cards, which presented the following situations:

- A rising hot air balloon
- A ball striking a skittle
- One rollerskater pushing on another
- A tug of war
- One steel block resting on another

These situations differ in complexity, so cards appropriate for investigating the understanding of each individual interviewee were selected. The rollerskater example is the only IAI situation used which is found in any South African textbooks (see p 41). However it does not occur in any of the books used as textbooks by the teachers and the students under consideration.

Each interviewee was first asked whether each of the two bodies in the situation exerted a force on the other one, rather than presupposing that he/she was aware of both of the forces in the interaction. The interviewee was then asked to compare the magnitudes of the two forces. Apart from T1 and T2, the interviewees were unaware that Newton III was the topic of investigation: they had simply been told that the interview was about "an area of mechanics". Furthermore, this section of the interview preceded any mention of Newton III. Thus most of the interviewees' answers were not biased or prejudiced in favour of Newton III.

4.2.2. Other questions

The remainder of the interview focused explicitly on Newton III. Questions were asked to ascertain:

- which formulation of Newton III the interviewee preferred (Section 2).
- whether the interviewee saw any and every pair of equal and opposite pair of forces as

a Newton III pair (Section 3).

- how the interviewee explained any conflict between his/her knowledge and actual use of Newton III (Section 4).
- how important the interviewee perceived Newton III to be in understanding the concept of force (Section 5).
- in what depth the interviewee taught Newton III, and which types of examples the interviewee used in explaining it (Section 5).
- how the interviewee perceived his/her understanding and teaching of Newton III as having developed (Section 5).

4.2.3. Types of Questions

Patton (1990) classifies the different types of questions which can be asked in an interview - the questions asked in this study are classified accordingly in Table 9 below. All of the questions referred to the present, apart from the last question which asked about past behaviour. A number of the questions are dichotomous: it was necessary to find out the interviewee's stand before probing further.

Table 9: CLASSIFICATION OF INTERVIEW QUESTIONS

TYPE OF QUESTION	QUESTION NUMBERS
Knowledge	1 2 3 4 6 7 8 10 11 12 13
Opinion	5 14 15 17
Experience/Behaviour	16 18
Feeling	9

4.3. PILOT STUDY

The interview was piloted with students S1 - S4 and teachers T1 and T2. With the students, Mr Foster Lungu, an Honours student in science education, was present during the interviews, and conducted two of the interviews (S3 and S4). The interviews were each analysed by the researcher and Mr Lungu, and interpretations then compared and discussed.

The teachers used in the pilot study were asked to comment afterwards on the interview and offer criticisms and ideas. The interview structure was adapted accordingly. A significant adaptation was made after T1's interview: T1 commented that, by starting with a relatively straightforward instance, the interviewer had effectively led T1. Thereafter the interviewer presented more complex instances first, and then included simpler instances afterwards if necessary.

In analysing the results, the pilot interviews have not been distinguished from the rest, although sections of these interviews where the interviewer was leading or probed insufficiently had to be ignored.

4.4. TRANSCRIPTION

The interviews were transcribed from the cassette tapes onto a word processor. Certain decisions had to made regarding format and punctuation, and these are outlined here. The process by which transcriber reliability was established is then described.

4.4.1. Conventions used

Opinions differ on the extent to which a transcriber should include punctuation. A verbatim, unpunctuated transcript is difficult to read, and as Kvale notes:

> "The verbatim transcribed oral language may ... appear as incoherent and confused speech, thus implying a lower level of intellectual functioning." (1988:56)

The intention was rather to provide meaningful and useful transcripts, which involved doing some interpretation and analysis whilst transcribing.

So punctuation has been used to convey what the researcher understands the intention of the speaker to have been. This does not mean that this is necessarily the way the speaker would have punctuated his/her statements or the way that another transcriber would punctuate - unavoidably the researcher's style of punctuation comes through. But it seems reasonable to claim that the interpretation, though not the only option, is valid. To make this process as transparent as possible, the criteria and conventions used are outlined in Table 10 (p 50). Examples of extracts from interview transcriptions are given in Appendices 2 and 3.

Table 10 : CONVENTIONS USED IN TRANSCRIPTION

SITUATION	DESCRIPTION	EXAMPLE
CHANGE OF DIRECTION	In conversation, a person may change his/her mind in mid-sentence, and reformulate what he/she is saying. A slash is used to indicate this.	I think / I could say
EXPRESSION	A transcript is not a full representation of a conversation as gestures, intonation and facial expression cannot be accurately represented. Pauses as well as some tones and gestures are indicated in square brackets, and words which receive specific emphasis which is helpful in understanding the meaning of the speaker are underlined.	[slowly] very
INDISTINCT STATEMENTS	If it is impossible to make out a word or words, this is represented by the word "indistinct" in square brackets.	[indistinct]
IRRELEVANT CHATTER	Statements which are judged to be irrelevant are represented by three dots.	...
INTERVIEWER'S ENCOURAGEMENT	Words such as OK, alright, fine etc, which the interviewer intersperses in order to encourage the interviewee (without leading) have not been included.	
STUTTERS	Some people repeat words as they formulate a sentence. These stutters, if transcribed, detract from the sense of a sentence and have been left out. Some people use the word "um" as a matter of course in conversation, so these have generally been omitted.	

4.4.2. Transcriber Reliability

In transcribing interviews, there needs to be some check that the transcriber is hearing correctly. Transcriber reliability was checked by working together with Mr Lungu on transcripts S1 to S4. Interviews S1 and S2 were transcribed by the researcher, and then the tape-recordings and transcripts were handed to Mr Lungu who listened carefully to the tape while reading the transcript, and noted any inconsistencies. One inconsistency was found, and Mr Lungu also queried a colloquial expression which was used by S1.

The above method of checking prejudices the checker in favour of the transcriber's version. For an unprejudiced check, interviews S3 and S4 were transcribed by both the researcher and

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CHANGE OF DIRECTION	In conversation, a person may change his/her mind in mid-sentence, and reformulate what he/she is saying. A slash is used to indicate this.	I think / I could say
EXPRESSION	A transcript is not a full representation of a conversation as gestures, intonation and facial expression cannot be accurately represented. Pauses as well as some tones and gestures are indicated in square brackets, and words which receive specific emphasis which is helpful in understanding the meaning of the speaker are underlined.	[slowly] <u>very</u>
INDISTINCT STATEMENTS	If it is impossible to make out a word or words, this is represented by the word "indistinct" in square brackets.	[indistinct]
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The above method of checking prejudices the checker in favour of the transcriber's version. For an unprejudiced check, interviews S3 and S4 were transcribed by both the researcher and

Mr Lungu, and the transcripts were then compared. Where they differed, the relevant portions of the tape were listened to over again by both the researcher and Mr Lungu, except where the discrepancy was over a word which made no difference to the sense of the sentence (eg would/will, the/this).

As a result of this process, for S3 and S4 respectively, 0,5 % and 0,9 % words (eg. the, sort of, by) were added to the researcher's transcript; and 1,2 % and 0,5 % words were changed. Only one of the changes altered the meaning significantly: for S4, "when you just have your velocity" was corrected to "let me just add velocity".

There were however some words over which agreement was not reached, generally because the speech of the interviewee was fairly garbled at those points. This amounted to 1,1 % of S3's transcript, and 1,0 % of S4's transcript. As a result of this, the researcher thereafter used "[indistinct]" on transcripts more frequently, instead of trying to make out words that were not clear.

Overall the agreement between the two sets of transcripts was sufficiently high to claim that transcriber reliability was achieved.

4.5. SUMMARY

All of the 16 interviewees were qualified or nearly qualified physical science teachers. Their teaching experience ranged from no experience (except for teaching practice as students during the HDE course) to very experienced. Each interviewee was asked questions using the IAI cards, and other questions relating to their understanding and teaching of Newton III. The pilot study involved two teachers and four students, and led to refinement of the interview guide as well as the transcription process. Transcriber reliability was proved by collaboration with Mr Lungu on four of the transcripts. Having covered the details relating to the interviews and their transcription, the actual analysis can now be considered - this is presented in the following chapter.

CHAPTER FIVE
ANALYSIS OF INTERVIEWS

The first step in analysing the interviews was to consider each interview on its own, making sense of the ideas contained therein. The second step involved considering the interviews together, comparing the various interviewees' responses to each question. This chapter gives the latter analysis, but also identifies patterns of response to be found in certain individual interviews. On the basis of these patterns, two hypotheses are formulated.

The questions in the interviews were asked in a specific order to minimise the effects of some questions on responses to others. However a different order has been used in this chapter, in order to develop ideas in a logical sequence. In some cases, a certain idea came through in the answers to more than one question. Thus from time to time references are made to sections of the interview other than the section under discussion, in order to elucidate a particular idea.

5.1. CONCEPT OF FORCE

The first question of each interview was simply "What in your understanding is a force?". This served a dual purpose: it helped to ease the interviewee gently into the interview, and it also checked that the interviewee's understanding of the term "force" corresponded with the interviewer's. Apart from S1, S2, T4 and T9, every interviewee included the standard "push or pull" description. S1 started with "It's something you apply"; S2 gave it as "something that acts on something else"; T4 launched into a more formal definition; and T9 responded in terms of Newton II.

However, the ability to define force does not preclude a person from holding unscientific ideas about the concept of force. So, although S1, S2, S5, S7, T5 and T9 gave a description of force which was not incorrect, their later use of the concept was not completely in line with scientific usage. As discussed in section 2.3 (p 9), there are two incorrect ideas which come through strongly when one looks at research which has been done on people's understanding of Newton III:

- Action and reaction forces can cancel (section 2.3.1, p 10).
- Bigger and faster bodies exert greater forces (section 2.3.2, p 11).

Each of these ideas was held by some of the interviewees.

5.1.1. Action and reaction can cancel

S2 gave an example of someone leaning against a wall and stated:

> "if they're leaning against a wall, then they're exerting a force on the wall, then the wall must be exerting the same force back, *otherwise the wall would be falling over.*"

The implication here is that the force exerted by the person on the wall and the force exerted by the wall on the person can cancel. (In fact, the reason that the wall does not fall over is because there are other forces acting *on* the wall which balance the force exerted by the person on the wall.) S2 applied this understanding of action and reaction consistently throughout her interview.

Similarly, T9 explained her problem with Newton III:

> "Because I take it if action causes reaction, they should be stable, they should be balanced. If I am pushing this [pushes tape recorder] it shouldn't move because action/ what I am applying to this is also applying a force back to me, so I'm expecting it to be stationary."

T5 showed a similar understanding at times, and also appeared to use the terms "force" and "resultant force" interchangeably.

5.1.2. Bigger and faster bodies exert greater forces

When T9 was asked for her understanding of force, she replied:

> "Well, a force to me it's something that involves mass and acceleration, the way I've understood from maybe reading of textbooks, ... but I think in yesteryears to me force was some sort of an external thing that makes things to be around or to move, sort of."

In other words, T9 started with the fairly standard preconceptions that force is needed to keep an object in position or to make it move (section 2.2.1, p 7). But, as a result of her study in physics, she had come to understand that force is defined in terms of the equation

$$F = ma$$

This is correct but it became apparent from her use of this idea in later answers that she had tied this up with the intuitive idea that bigger and faster bodies exert greater forces. So, instead of interpreting F as a force exerted *on* a mass m producing an acceleration a, T9 had interpreted it as the force which is exerted *by* a mass m with an acceleration a. This understanding was reported amongst South African students by Jordaar (1993b, see section 2.3.2, p 12). S5 demonstrated a similar understanding in some answers.

5.2. FORM OF STATEMENT OF NEWTON III

Question 5 of the interview asked the interviewee his/her opinion on the best way of stating Newton III. As mentioned (section 2.5.1, p 18) researchers point to the need to be careful about the form in which Newton III is stated. A good form is one that refers to two bodies and makes it clear that the forces act on two different bodies. South African textbooks make use of two forms (see Table 2, p 38): form A (If body A exerts a force on body B, then body B exerts an equal and opposite force on body A) and the incomplete version of form B (For every action there is an equal but opposite reaction). The latter is more popular in the textbooks currently in use. However, as discussed (section 3.3.1, p 24), form A is superior, and is in fact the form which appears in the core syllabus.

5.2.1. Students

The textbooks used by the students for first year mechanics (Giancoli, 1991; Kane and Sternheim, 1983) both give form A (in the form "If one object exerts ..." - Table 4, p 40). Giancoli also mentions the incomplete version of form B but notes its inferiority. However only two of the students, S3 and S4 (the only students with any Std 10 teaching experience), gave form A, and both started stating form B and then corrected themselves. For example, S3 stated:

> "For every action that is applied to a body / OK, let me say it right: if body A exerts a force on body B, body B will exert a force on body A that is equal in magnitude to the original force, but opposite in direction."

"Let me say it right" indicates that he was aware that the form which he then gave is superior to the form which he started with.

However he made the mistake of adding "will", which puts the second phrase into the future tense, and thus detracts from the simultaneity of the two forces. (As mentioned in section

3.3.3, p 25, this variation is also given in the textbook by Pienaar *et al.*, 1987, and in two of the teachers guides). Interestingly, S6 claimed that he:

"wouldn't have the faintest idea of any formulated way of stating it"

but then in explaining what Newton III means, he gave form A (also using "will" in the second phrase).

The remaining four students all gave the incomplete version of form B, with S1 and S2 initially unable to recall just which law Newton III is. However the lecturer who had taught the JCE students (S5 - S7) physics in their first year said he followed Giancoli closely, and the lecturer who took the Wits students (S1 - S4) for the "Physical Science Additional Studies" course (mentioned on p 46) had pointed out that such a version was incomplete and inferior. So these students probably recalled the form they were originally taught at school, a form which is appealing because it is easily remembered. S2 could remember of the lecture on Newton's laws that:

> "There's a catch which I would have to go over because we were taught about this - there's a catch and in schools there, it's always taught without this little phrase at the end..."

The "catch" which she refers to is of course the second half of the form B version of Newton III, which is usually omitted. Her interpretation was that somehow this "catch" changed the meaning of Newton III.

5.2.2. Teachers

All of the teachers interviewed used one (or more) of the textbooks which give Newton III as the incomplete form B, except for T2 who had used Broster and James (which gives form A) but was not teaching at the time. Not surprisingly, then, more teachers gave the incomplete form B. T1, T2, T6 and T7 gave form A. However T1 and T2 put the second phrase in the future tense. Whilst they may have been influenced by the IMSTUS guide (Saayman, 1988), it is likely that this was an inadvertent slip. T7 noted that

"people often say action-reaction, but it can be a bit of a problem"

which reflected her awareness of the inferiority of the incomplete form B.

Similarly, T4 and T8, although they gave the incomplete form B, did so with acknowledgement of the problems associated with it. T4 explained:

> "Well, we do tend to say for every action there's an equal and opposite reaction, but I think that's misleading. One needs to say that there are two bodies involved, that it cannot / the equal and opposite actions cannot occur on the same body, ... So when I define it, yes for quickness I say for every action there's an equal and opposite reaction, but I always write it there in little formula-type thing to show that body A / the force on body A equals *minus* force on body B. So yes I suppose I do use the recognised definition, but I don't really like it, and I always point out to my kids that there's got to be two bodies involved."

The phrase "recognised definition" implies that T4 sees the form given in textbooks as somehow more legitimate.

T9's incorrect interpretation of the equation **F** = m**a** (section 5.1.2, p 53) conflicted with her understanding of Newton III - a conflict she realised and articulated well.

5.2.3. Statement and application

Stating Newton III is one thing; applying it broadly is quite another. Yet there seems to be a strong link between the form in which someone states Newton III and their degree of success in applying it broadly. The technique of Interviews-About-Instances (IAI) described in section 4.2.1 (p 47) was used to discover whether each interviewee applied Newton III in practical situations. The responses given are discussed in the next section.

For 12 of the 16 interviewees, the correlation between statement and application was as follows:

- 6 interviewees (S3, S4, T1, T2, T6 and T7) gave Newton III in form A, and applied it correctly to every situation which they were presented with.
- 6 interviewees (S1, S2, S5, S7, T5 and T9) gave Newton III in the incomplete form B and applied it correctly in at most half of the situations which they were presented with.

Of the remaining four interviewees, T4 and T8 gave the incomplete form B and applied it correctly throughout, but acknowledged the inferiority of this form. T6 did not give a statement of the law. Thus T3 was the only person who did not indicate any reservations about giving the incomplete form B, and yet applied Newton III correctly throughout.

Thus it seems reasonable to hypothesise:

H1: **A teacher or student teacher who gives Newton III in form A is more likely to apply it correctly to all situations than one who gives Newton III in the incomplete form B.**

Of course, given the small and non-random nature of the sample used in this study, this hypothesis cannot be assumed to be broadly generalisable. However, it does seem logical, since form A is a superior form insofar as it makes it clear that the two forces act on two different bodies. The hypothesis also applies exceptionally strongly with the sample in this study. Thus it can be tentatively suggested that this hypothesis might well apply more broadly than this sample.

5.3. APPLICATION OF NEWTON III: IAI CARDS

What follows is a discussion of each IAI card used and the responses of the interviewees. Each interviewee was asked **whether each of the two bodies in the situation exerted a force on the other one**, and then asked to **compare the magnitudes of the two forces**. As mentioned (section 4.2.1, p 47), at this stage of the interview, most of the interviewees were unaware that Newton III was the topic of investigation, so that their answers were not biased or prejudiced in favour of Newton III.

5.3.1. Hot air balloon

T9's response to the hot air balloon situation is interesting. When asked whether the earth exerts a force on the balloon, she applied Newton III, but incorrectly, as implying that there must be a pair of forces acting *on* the balloon. Since the forces on the balloon are balanced (no acceleration), she concluded that the force exerted by the earth is the reaction force to the upward force. This corresponds to the finding of Terry *et al.* (1985) that many students invoke Newton III as a reason for equilibrium (section 2.3.1, p 10).

When asked about the force exerted by the balloon on the earth, T9 again made reference to Newton III, this time applying it correctly. When asked to compare the sizes of this pair of forces, she answered, consistent with her earlier logic, that the more massive earth would exert the greater force, but then articulated again the conflict which she perceived between her understanding of force and Newton III:

"But then still I have a problem because somewhere Newton's saying, irrespective of the masses of the two things, they would still exert the same magnitude of force. But according to me, it's not clear that much to me, how possibly is that when something is small and the other one is big, and you expect them to exert the same force."

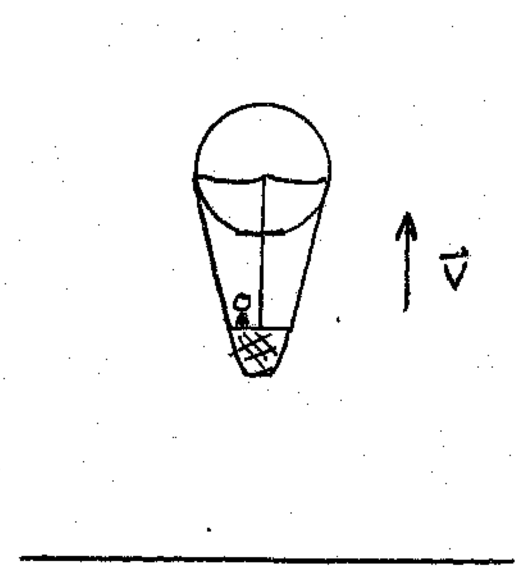

Figure 2. HOT AIR BALLOON

Four of the students with no Std 10 teaching experience (S1, S2, S6 and S7) saw the force exerted by the balloon on the earth as being either non-existent or very small, but, unlike T9, did not identify any conflict with Newton III. S1 expressed her answer with reasoning in terms of mass, similar to T9:

> "I suppose in relation to the earth its weight / its mass would be too little to actually, sort of, exert a force. I don't know. Maybe it would but I mean the planets do, the moon does affect the earth, so that is an object - maybe it would. {indistinct} not to any great degree."

Interestingly, S6 made reference to Newton's Law of Universal Gravitation (LUG), quoting the equation in full, yet did not appreciate that this gives the same magnitude for each of the pair of forces.

Law of Universal Gravitation

Apart from T9, all of the teachers identified the forces as equal in magnitude, although five answered, quite correctly, in terms of LUG rather than Newton III. However, it was eye-opening to discover that T5 and T8 did not see Newton III as including LUG. When asked later in the interview about whether there are any exceptions to Newton III, T8 (a very experienced teacher) first discussed centrifugal and centripetal forces, and then, unprompted, moved on to gravitational forces. The transcript of her gradual realisation that Newton III *does* include LUG makes for fascinating reading (Appendix 2). At the end of the discussion, she agreed that she had definitely seen Newton III solely in terms of contact forces prior to the interview, and added:

> "You see one always thinks of a horse pushing a cart, [indistinct], a rocket carrying its fuel ..."

In section 3.7 (p 33), it was observed that all but four of the twenty-two textbooks examined limit their examples to contact examples. So the examples used give the impression that Newton III applies only to contact forces, despite there being no restrictions given in statements of Newton III. For T8 this impression remained unchallenged until the interview.

5.3.2. Ball and skittle

The next IAI card showed a ball rolling towards a skittle. This situation was investigated by Brown (1989), who found that only 5 % of his sample (students who had studied Newton's laws) thought that the forces were equal in magnitude, 94 % saw the ball as exerting greater force. (See section 2.3.2, p 11 for more details of Brown's study.) The sample in the present study fared far better: all but T2 were asked on this situation, and only S1, S2, S5, T5 and T9 thought that the forces were not equal.

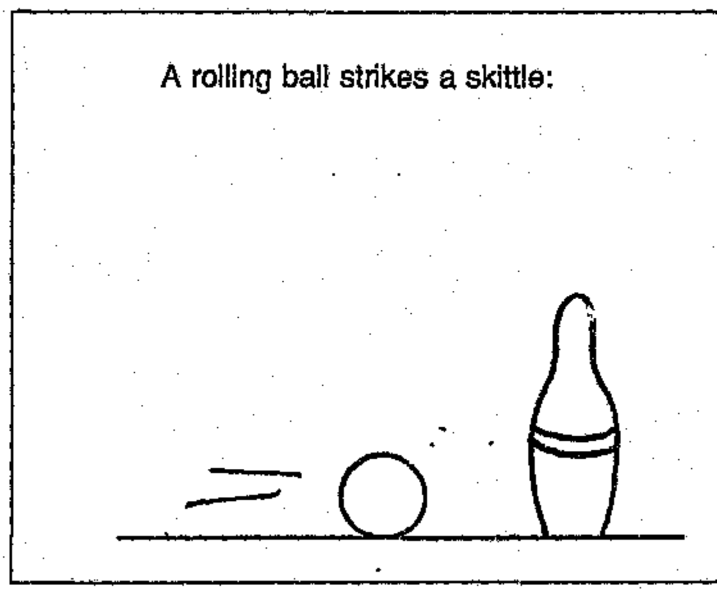

Figure 3. BALL AND SKITTLE

T9's answer was consistent with her previous responses in which she applied F = ma incorrectly. She felt that if the masses were equal, then the forces would be equal. However given the situation of a more massive skittle, she referred to the velocity of the ball, indicating that she was not sure how that would affect the situation.

Despite having applied Newton III correctly in discussing the hot air balloon, S5 applied the same logic as T9 on this example:

> "... force is mass times acceleration - so obviously the one with the greater mass would have greater force, would apply a greater force."

S1 and S2's answers reflected the "forcefulness" idea: they both felt that the moving ball should exert a greater force. S2 explained:

> "Well, the thing is, the ball has got momentum."

S1 took the idea further, feeling that once the skittle started moving, it would also "have" force:

> "Because there's movement I suppose - the skittle isn't moving. Movement would have something to do with it, but then once the ball has hit, the skittle will move. Maybe its force would most likely be equal at that stage - once it's hit."

System Confusion

T5's answer revealed a very interesting confusion in the use of the term "system". The term is used in two different ways in mechanics: a "system of forces" are forces all acting on *one* body, and an "isolated system", in which momentum is conserved, generally refers to *two* (or more) bodies, with no external unbalanced forces acting on the system. When asked why he felt the force exerted by the ball would be greater, T5 used system in the first sense, and then went on to talk implicitly about a system in the second sense - it appears that he did not register the difference between the two:

> "Because you will not / the system will not be in equilibrium afterwards. Because the momentum before must equal the momentum after."

This answer reflects the problem which confusion of the two types of system can lead to: if a system of forces is seen as involving more than one body (like an isolated system) then all of the forces acting on two bodies can be added together. According to this logic, the Newton III pair of forces between the ball and skittle can be added together. Thus, since a resultant force of the "system" is necessary to account for the changes in motion of the ball and skittle, the ball must exert a greater force than the skittle.

In explaining why one body exerts a greater force than the other in a subsequent situation (the tug of war), S2 demonstrated a similar confusion regarding the term "system":

"The forces would be opposite but not equal, because if they were equal, then the system would be in equilibrium, and none of them would be moving."

The system which she refers to is that of both bodies, but she has used this in connection with forces in equilibrium. Such confusion of the two applications of the term "system" may well be part of the reason for the common incorrect idea that action and reaction forces can cancel (section 2.3.1, p 10 and section 3.5.1, p 28).

5.3.3. Rollerskaters

The situation of two rollerskaters with one pushing against the other is very similar to one in the study by Brown (1989, see section 2.3.2, p 11): two people sitting on office chairs, with one pushing against the other. Before instruction only 17 % of the students thought that the forces would be equal - this rose to 44 % after instruction. 93 % of those who were still incorrect thought that the pusher would exert the greater force.

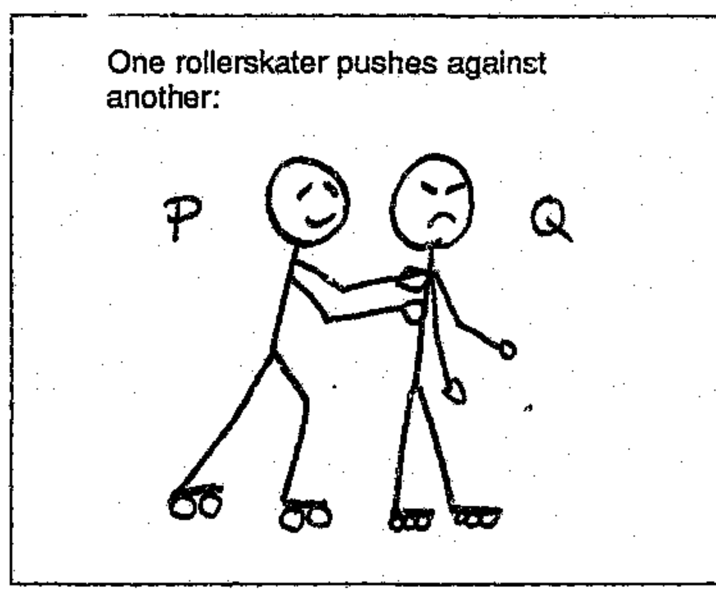

Figure 4. ROLLERSKATERS

As described (section 2.5.2, p 19), the situation of two rollerskaters was investigated by Terry and Jones (1986), who found that 90 % of their sample could answer questions about two equal mass rollerskaters correctly, but they put this down to the fact that most had seen this demonstrated in the classroom, since only 50 % answered questions about skaters of unequal mass correctly.

Force and Motion Link

In the present study, of those asked about the rollerskaters (all except S1, S2 and S3), all eventually ended up stating that the forces exerted by the two skaters are equal. However, T3, T5 and T9 asked about the movement of the skaters. This suggests a strong association of force with movement - that the movement of a body is an indication of the strength of a force exerted on it. Such an idea stems from the "supply of force" notion (section 2.2.1, p 7). If the interviewees assumed equal movement of the skaters meant equal forces, then the correct answer appears to have been given for the wrong reasons.

However T3 and T5's answers were not clear and the interviewer did not probe sufficiently, so conclusions cannot be drawn. T9's response was clearer:

> T9: "Because / what is happening, is P pushing Q and Q is moving, as he's pushing? Or is he stationary?"
> INTERVIEWER: "They're both free to move, ... we've reduced the friction by putting them on rollerskates."
> T9: "So if they are both able to / free to move then it means they are exerting the same amount of force on each other."

It appears that T9 equated "free to move" with actual movement. Since she saw both as moving (presumably equally), she felt that the forces must therefore be equal. Since she understood $F = ma$ as defining the force which can be exerted *by* a body, it could well be that she understood the forces exerted *on* a body in terms of the "supply of force" idea.

Opposite but not Equal

S5 referred immediately to Newton III when asked whether Q exerts a force back on P:

> "Yeah, Newton 3. It would have to be exerting a force."

But when asked about the relative sizes of the forces, she responded:

> "... I would think that P would be exerting a greater force on Q than Q on P."

This suggests that someone can absorb the fact that every force exerted has a partner, without appreciating that the forces are equal in size. When the conflict in her statements was pointed out to S5, she resolved it:

> INTERVIEWER: "You said Newton's third law. How does that fit in there?"
> S5: "Um. For every force or action there's an equal and opposite reaction. So rightfully it should be equal. The force that P exerts on Q should be equal to the force that Q exerts on P."

5.3.4. Tug of war

The situation of two teams engaged in a tug of war is similar to the classical horse and cart situation. A rope was deliberately not included in the illustration, so that the forces on a rope would not have to be considered. The intuitive response to this situation is that the team which pulls more strongly wins, based on the incorrect idea that the action-reaction pair of forces can cancel. In fact it is the team which exerts a greater force on the ground which wins. Mwakapenda (1994) found that only 1 of 7 Std 9 and 10 South African physical science teachers who attended an inservice workshop thought that the forces were equal.

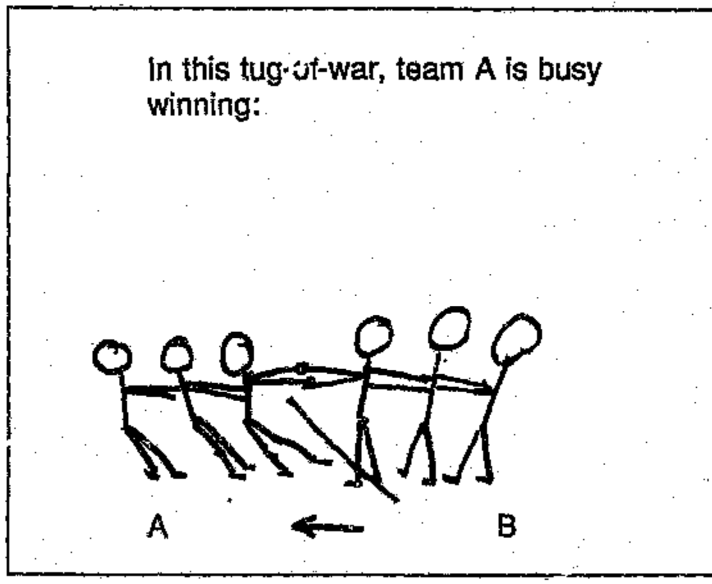

Figure 5. TUG OF WAR

Giancoli, which is the textbook used by most of the students for first year physics, devotes nearly a page to an explanation of why a cart moves when it is pulled (1991:74). But the logical argument presented had evidently not had a lasting effect on S1, S2, S6 and S7, who gave the response that the winning team exerts a greater force. T5 also answered in this way.

S7 then modified his answer to:

> "the force would only be different if one of them was accelerating in the opposite direction."

In other words, S7 thought the forces could cancel, but he took cognisance of Newton's first two laws of motion, according to which rest and constant velocity are equivalent situations. Maloney (1984) found the same interpretation with a number of his students (section 2.3.2, p 12).

S5 stuck with her **F = ma** interpretation, stating that probably the one with the greater mass or the greater acceleration would win.

Action and reaction interpreted as "one force"

S3, S4, T2 and T6 were the only other interviewees who were given this situation, and they all gave the forces as equal in magnitude. However it later emerged that S4 had resolved the conflict between the scientific answer and the intuitive response by seeing between the two teams TWO action-reaction pairs: team A deliberately exerts a force which has an equal and opposite reaction force, and team B exerts *another* lesser force which also has an equal and opposite reaction force. In other words, S4 resolved the fact that team A is winning by seeing them as exerting a greater force than team B, but saw each of those two forces as having an equal and opposite reaction partner, i.e. four forces between the two teams. S4 had not considered the friction forces between the teams and the ground.

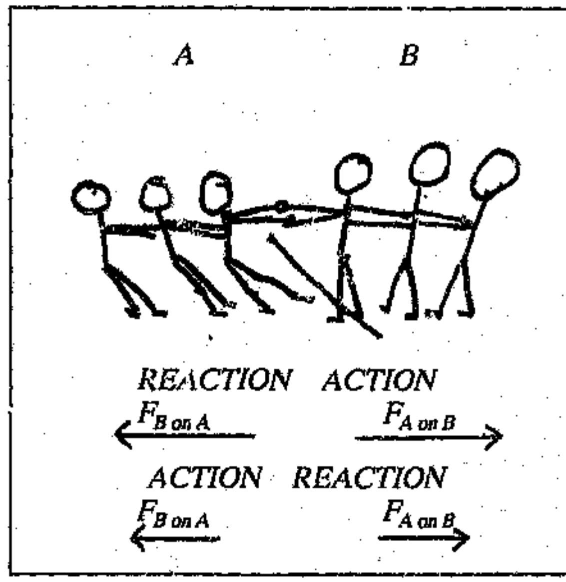

Figure 6. ONE FORCE INTERPRETATION

S7 demonstrated a similar "one force" understanding. After stating Newton III he was asked to explain it, and replied:

> "Something you apply a force to must [pause] give a force in the opposite direction. (How do I explain it?) Everything you apply a force to must give that same force back to you but in the opposite direction."

Similarly, in discussing the rollerskaters, he had stated "there is only one force" in referring to the interaction, and in further discussion of the tug of war (after staring Newton III), he explained:

> "... if B wasn't exerting a force at all, and A exerted that force, and B wasn't exerting a force, A would seem to feel a force that B is exerting on it due to the fact that it/ it would be A's force in other words. *A exerting a force on B will feel as if that same force is being exerted by B on it.*"

This "one force" understanding very neatly compromises between Newton III and intuitive understanding. Moreover, it does not easily come to light, since the person holding it could still give correct answers to diagnostic questions (as S4 did).

5.3.5. Steel blocks

The situation of two stationary steel blocks is analogous to the example commonly quoted for Newton III of a book (or other object) resting on a table. It was only given to S3 and T1 (who were certain the forces were equal) and to the interviewees who had not considered any of the pairs of forces in the other situations equal: S1, S2 and T9.

S1 and T9 both felt that the more massive block would exert the greater force, in line with the idea that bigger and faster bodies exert greater forces. T9 once again articulated the conflict between Newton III and the idea of the more massive object exerting the greater force.

> "Aren't they equal? [pause] I don't know - the thing is that I've got this thing of Newton's law in my head ... that action is equal to reaction always, and different bodies / this force exerted on different bodies. But I'm not sure of the magnitude of the forces, as to whether, because the B is smaller than A, would it exert a smaller force too, but then still, contradicts the law -would that be the case? But the law says there would be the same magnitude of force, if there was 200 Newtons exerted on this one, this one also exerted 200 Newtons on this one too. But I know they are ... directly proportional, the mass and the force, because F equals to m a."

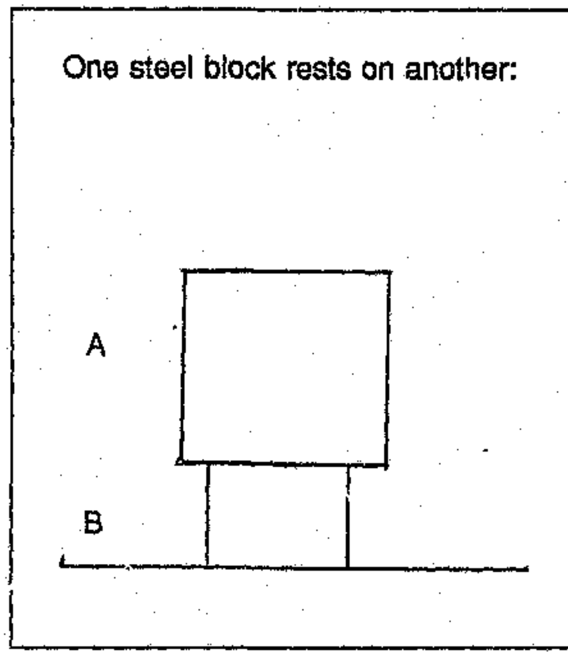

Figure 7. STEEL BLOCKS

S2's answer was consistent with her understanding that action and reaction can cancel:

> "Well, I imagine they're equal, because it's not *going* anywhere."

5.3.6. Relative difficulty of the situations

Since not everyone interviewed was given every IAI card, it is meaningless to simply compare the total number of correct answers for each situation to assess the relative difficulty of the situations for the interviewees. However, the four interviewees who applied Newton III correctly in only some of the situations were all given the same situations (all except the steel blocks), and so their answers can be compared. For them the most difficult situation appears to have been the tug of war, where not one of them regarded the forces as equal. The remaining three situations seem to have been on a par in terms of difficulty for these interviewees.

All of the interviewees except T1 and T3 were also asked which of the situations they regarded as being more difficult to understand (question 14). This produced a range of responses, some of which contradicted each other. For example, T6 felt that the examples involving people (the rollerskaters and the tug of war) were more difficult. But S4 identified the problem of forces exerted by inanimate objects (section 2.2.3, p 9 and section 3.6.2, p 33):

> "I think what makes it a little bit difficult with this one [ball and skittle] also is the fact that it's inanimate objects ... and you always expect forces to be applied when things are / ... even if they aren't alive, but they must have at least those characteristics, you know like maybe a machine or something that can apply a force, ..."

However, S4 did observe that the rollerskaters presented a bit of a problem:

> "It's two animate objects and the one [P] is pushing the other one [Q] physically ... and the other is not really pushing back in the same sense that this one [P] is pushing that one there."

T2 and T4 also saw the rollerskaters as not so easy. T2's response (which tied up with her slight hesitation when originally presented with this situation) was in terms of the internal forces at work:

> "It's sort of rather like saying, you know, "does this arm exert a force on this hand?" [indicates her arm and hand] ... so that's quite hard to draw a line where does the one push start ..."

S4 also made the distinction between forces which are exerted over a period of time and forces which are exerted "instantaneously" (such as with the ball and skittle) - seeing the latter as more difficult. Strangely, despite his choosing of the ball and skittle situation as the most difficult, S4 had in fact answered it easily and confidently, but shown some hesitation with the rollerskaters. Perhaps his answers to the question of difficulty reflect the problems which he has discovered his students have.

Certainly, T4 and T7 immediately answered the question in terms of which situations they find students have more difficulty with. T7 answered in terms of Newton II: she saw the hot air balloon as more difficult for students to understand, because of the fact that the balloon is moving in the opposite direction to the force being exerted on it by the earth.

5.4. UNIVERSALITY OF NEWTON III

Jordaan (1993b) notes that students tend to introduce "extraneous conditions" to Newton III, such as the idea that it only applies to bodies in equilibrium. The first interview question which addressed the universality of Newton III was question 8, which asked whether the law applies to any pair of bodies which interact. In addition, those interviewees who had not given all the pairs of forces as equal in magnitude were asked whether they thought Newton III applied in each of those situations.

In response to question 8, not one of the interviewees picked up on the limitations with forces applied over large distances (see section 3.5.4, p 30). Most of the interviewees (T1 - T7, S3 and S4) answered that it applies to all bodies. But it was interesting to see the hesitancy of the answers of even those who had been completely confident about their answers to the IAI cards. For example T7 (a very experienced teacher) responded:

> [Pause, hesitantly] "Not to my knowledge. I think it's any interaction. I think."

This may be due to the fact that the question was in effect slightly leading, implying that exceptions do exist, as S2's response reflected:

> "There must be limits, because otherwise you wouldn't be asking."

5.4.1. Status of scientific laws

S5's answer to question 8 is interesting:

> S5: "To most."
> INTERVIEWER: "Okay. Would there be any exceptions?"
> S5: [Giggle] "There's exceptions to every rule."

S5 had interpreted scientific laws in the same way as, for example, language rules which always have exceptions, rather than as universal natural laws. T9 reduced the status of scientific laws as well:

> "I think because it's just a law - it's just a scientific law developed by somebody, there are other things probably that it does not cover."

She also suggested that it had perhaps been superseded by more recent research.

5.4.2. Only contact-push situations

As described (section 5.3.1, p 58), T8 had made the assumption that Newton III applied to contact examples only. S6 and S7 made a similar assumption - in fact they gave remarkably similar answers to the question of exceptions: both first indicated that there were no exceptions, but then felt Newton III did not apply to the hot air balloon situation, and so concluded tentatively that it only applies to contact forces. (This tallied with the fact that S7 had referred to the fact that the bodies were in contact when discussing two of the IAI situations.) Both S6 and S7 had seen the ball and skittle, and the rollerskaters as exerting equal forces, but both had felt that the winning team would exert the greater force in the tug of war. When the tug of war was raised again, S6 looked for some justification for his answer, and picked on the distinction between pushing and pulling. His argument (Appendix 3) is an interesting example of an attempt to force the theory to fit that which "makes sense".

S7 had alluded to the difference between pushing and pulling, when discussing the tug of war IAI card initially. He had spontaneously compared the tug of war situation to the rollerskaters, but had concluded of the skaters

> "You've got a different situation here, because they're separating."

This tendency to think of Newton III only in terms of pushing examples corresponds to the clustering of examples in this category found in South African textbooks (see section 3.7.1, p 33, and p 41).

5.4.3. Only stationary bodies

S1 and S2 limited the situation even further: after some discussion, each one concluded that it applied only to stationary bodies. But S1 had said earlier that the larger of the (stationary) steel blocks would exert a greater force (see section 5.3.5, p 65). When this IAI card was presented to her again, she realised the conflict:

> INTERVIEWER: "Earlier you said that A exerts a greater force..."
> S1: [Quickly] "Ja, I know that's why I'm thinking, that's why I'm thinking. I did say that but now I'm saying no they've got the same forces - which is not my original 'no'."
> INTERVIEWER: "OK, you said Newton's law applies to stationary bodies though."
> S1: "Ja, um."
> INTERVIEWER: "You can think it through aloud if you want to a bit - you don't have to be certain of these things."
> S1: "No, the only thing that's bothering me is the different sizes of the objects. If they were the same object, then I'd say definitely, but they're not. But then when I think of a man and car, that's not the same size object either - so maybe I'd say Newton's law does apply there."

S1 had quoted the example of the man and car in explaining Newton III - it is probably an example she had come across in lessons or in textbooks. The assumption that a larger body exerts a greater force is consistent with the "forcefulness" idea which was also reflected in an earlier answer of S1's (see p 60). Here and elsewhere (see p 58) S1 showed her ability to compare different situations, abstracting the common physics. Yet it appeared she had not abstracted the physics of the man and car example successfully. This points to the apparent simplicity of Newton III, which is in fact deceptive.

5.5. NEWTON III AND INTUITION

This deceptive apparent simplicity of Newton III, together with the fact that research has sh[illegible] concept of Newton III is generally not an intuitive one prompted question 9, w[illegible]viewee whether the law made sense. Interestingly, there is no pattern in people[illegible]meone who had applied Newton III confidently to the IAI situations was as lik[illegible] to give a [illegible]ve response as not, as was someone who had not used Newton III in every situation. T2 hinted at a possible reason for this: towards the end of her interview she commented:

> "I mean no-one really believes this stuff ... partly it's a matter of being familiar with it."

In other words, it seems she had not assimilated Newton III into her understanding of the world, but had learnt to use it. However, others such as T8 appear to have assimilated it completely:

> "I've lived with it longer than I have / than before I was introduced to the law. So to think back all that time before having perhaps had to think about Newton 3 / I would like to suggest it's intuitive, because there's quite a physical interaction which goes on - there so many physical examples that there must be an intuitive response to that, I would say."

T2 claimed it made sense, though she did not use it in the IAI's. This again reflects the deceptive apparent simplicity of Newton III. S7's response to question 9 spells out this apparent simplicity beautifully:

> "... It did, it did until now. Um, ja I always thought it was the most easy / the easiest thing to understand. I haven't really dealt much with it since school though. But I always thought it was quite a simple thing to understand. But ja, no it's/ it doesn't make very much sense now, to be honest with you."

T5, who had not met with too much success in applying Newton III, expressed his dilemma as follows:

> "It makes sense to me in theory, but in practice, no. I do understand that if a force is applied to a body, then the body will apply a force to it but uh - I think in theory, yes, but not in practice."

The distinction between "in theory" and "in practice" again points to the deceptive apparent simplicity of Newton III: "in theory" seems to refer to the simple statement of the law, which looks straightforward, while "in practice" refers to the application of Newton III to situations, which T5 had demonstrated his difficulty with.

5.6. NEWTON I VERSUS NEWTON III PAIRS

As noted in sectk .5.1 (p 28), some textbooks give the impression that Newton III results in a state of equilibrium, i.e. there is a confusion between Newton I and Newton III pairs of forces. Furthermore, Terry and Jones (1986) found that some students, having been taught Newton III, invoked it as a condition for equilibrium (section 2.3.1, p 10). To ascertain whether teachers also make this kind of error, questions 10 and 11 were included in the interview, which asked about the forces acting on a pen lying on a desk.

The crucial element that needs to be recognised here is that two forces acting on one object cannot be an action-reaction pair. The importance of realising this was emphasised by three of the interviewees who applied Newton III correctly in all of the IAI situations. For example, after answering that the law made sense to him, S3 added:

> "but I think the thing is that have to be aware of that the action and reaction forces have to be on separate bodies / have to occur on separate bodies. I think if you bear that in mind, then it makes sense."

T4 gave the emphasis when stating Newton III (see section 5.2.2, p 56), and T8's response to the question about exceptions to Newton III included the following:

> "I always try to identify, number one, are there two bodies because if there's only one body, Newton 3 doesn't apply and I think this is where most people make a mistake talking Newton 3 glibly and they're discussing one body. So there must be two bodies - the one body must act upon the other and therefore the other one reacts upon the one."

Since the discussion immediately preceding questions 10 and 11 had been about Newton III, most of the 11 interviewees who were asked about the forces acting in the situation of a pen lying on a desk automatically gave their answers in the form of Newton III pairs, for example T2 replied:

> "Well, the pen's exerting a force on the table, and the table's exerting a force on the pen, and the earth's exerting a force on the pen, and the pen's exerting a force on the earth."

Obviously, everyone who gave a Newton III pair of forces was able to correctly identify them as such. But the interviewer failed in many cases to also check that the interviewees could recognise that two forces acting on one body are NOT a Newton III pair. Thus no broad conclusions can be drawn from this section of the interview.

However, some of the answers given are interesting in that they express the confusion about the weight of an object noticed in some textbooks (section 3.5.1, p 29). T5 was asked to give some of the forces acting on the pen, and replied:

> "Well there's a force, gravitational force pulling down towards the earth, force that's created by gravity, on the surface [table], and a force from the surface [table] on the body [pen] that's equal and opposite to that force."

He mentions the gravitational force on the pen, but specifies it as a force acting "on the surface". As noted, this mistake is also made by some textbook authors, who give the weight of an object as a force exerted *by* that object rather than a force exerted *on* it. T5 saw the two forces he gave as an action-reaction pair.

S4 and S7 both saw a strong link between the weight of the pen and the force which it exerts on the bench, since the former causes the latter. For S7 the causal link meant that the two forces on the pen are an action-reaction pair:

> "because the desk is only exerting a force on the pen because of the weight of the pen."

The problem seems to be his interpretation of the misleading "action-reaction" terminology.

S4 seemed to confuse the two forces, using them interchangeably:

> "The weight of the pen and the force that the table exerts on the pen upwards - those are reactionary forces. I mean they are the one / the pen is exerting a force on the table but it's due to its weight, OK so due to gravity, and so the reactionary force to that particular force is the force the table exerts on the pen. I'm not sure if that answers your question."

When he was asked specifically about whether the two forces acting on the pen would be an action-reaction pair, he answered in the affirmative.

The most surprising answer came from T8, whose emphasis on the fact that the forces act on two different bodies is quoted (p 70):

> "So the bench rests on the floor so gravitational force down on the floor supplies a reaction force up otherwise the bench would go down."

Here she first gives the weight of the bench as a force exerted on the floor, and then implies that the two forces cancel. In discussion, she also indicated that the two forces on the pen were an action-reaction pair, and that the two forces on the bench were an action-reaction pair. When the interviewer probed further, she corrected herself.

5.7. THE TEACHING OF NEWTON III

5.7.1. Importance

Question 15 was designed to assess teachers' feelings about the significance of Newton III in school science. However, particularly in the context of an interview which had focused on Newton III, it turned out to be very leading. "How important" implies that it is important, and so interviewees tended to find some or other reason for its importance. (A better question would have been "Do you think this law is necessary in school science? Explain"). In fact T6 was the only interviewee who expressed a negative answer:

> "It has its place but I think we overemphasise things which we actually shouldn't at the level the children are at - I would rather see us emphasising principle of moments and things which the children can actually verify practically, simply in many cases themselves. Do the Archimedes principle, the upthrust - all that sort of thing which can be done with simple practical apparatus, rather than these. It's a bit theoretical for the children, this sort of stuff, *I* think."

So it is not particularly meaningful to analyse interviewees' responses to this question. However, two responses are worth looking at. S3 stated:

> "I think that in terms of forces what it would mean is that nothing happens in isolation, ..."

This idea was also expressed by S4 when discussing the examples which he uses in teaching. He felt that the example of a rollerskater pushing against a wall is useful because it shows that a body "experiences a force when it exerts a force."

5.7.2. Position in syllabus

S6, T3 and T4 all strongly recommended introducing Newton III in Std 7. T4 explained:

"You have to because ... if you don't introduce it then, there's no ways, they've got so many preconceived ideas ... "

T7 deals with it in Std 9, when vectors are dealt with. When the suggestion of introducing it in Std 7 was put to her, she felt that Std 7 students "could handle it" but that the teacher would need to be "very careful". T8's response to the idea was:

"Not a bad idea at all. ... There's no reason why they shouldn't start thinking about it. ..."

But T6 (who felt it was unnecessary anyhow) and T2 did not think it was a good idea.

T8 (a very experienced teacher) felt that in Std 10:

"It must then only come after the momentum concept ... it's an extension of that concept."

This reflects the organisation of the previous syllabus, not the current one, and hence also of the older textbooks (see section 3.2, p 24). Of course, momentum conservation and Newton III are closely linked - there are a lot of situations which can be explained by reference to either. T7 also expressed the link between the two - she felt that the importance of Newton III in teaching is that:

"it brings in the whole conservation of momentum."

But too strong a connection between the two can lead to the impression that, like conservation of momentum, Newton III can only be applied to isolated systems. In explaining her statement of Newton III, T8 had spoken about the momentum of a space rocket and the equal and opposite momentum of its spent fuel. Later in the interview, when asked whether she would use a horse and cart type example, T8 said she would not:

"Because I think/ you see it's not an isolated system. An isolated system is much easier to discuss. And I always say to them, if you're asked to discuss Newton 3, go into an isolated system, think about a rocket in free space."

Such a close connection is perhaps also linked to the confusion of the concepts of momentum and force, and the use of the term "system", found in S2 and T5's answers (see p 60).

5.7.3. Examples used

Question 16 asked what examples the interviewee used or would use in teaching Newton III. A variety of examples were given, most of which can be found in one or other textbook. The only example which was mentioned more than twice is that of two people on skateboards/iceskates/rollerskates, which was raised by S4, T2, T7 and T9. The fact that this was one of the situations on the IAI cards probably influenced people's remembering of this situation. Apart from this there were no recognisable patterns in the answers given.

S3 and T4 both made interesting comments regarding the depth of examples used. T4 pointed out that one has to use examples involving moving objects,

> "because otherwise they think it [Newton III] only applies to stationary bodies".

In other words, students tend to place limitations on the universality of Newton III if they are not shown all types of examples. S3 felt that a teacher who left out more difficult examples was just "covering up" since students were going to come across such examples anyway.

5.7.4. Influence of external examination

T1, T4 and T6 all made reference to the effect which the external matriculation examinations had had on the attention which they have paid to Newton III in their teaching. T6 noted:

> "Well, I suppose I would agree with [a chemistry examiner] when he says that the exam papers promote development in teaching rather than the other way round - you know putting the questions in, we're going to try and find out about it and teach it a bit better."

She felt that her teaching had probably changed since a question on the tug of war was included one year.

Both T1 and T4 felt that the fact that Newton III was not examined much had influenced them considerably when they had started teaching. As T1 put it,

> "It was something that wasn't questioned very much in papers - very, very few questions on it. The application of his third law was *so* vaguely glossed over in textbooks and everything else: if you knew how to quote it, that was all that was actually necessary - a real understanding of it wasn't required. So I got round on that level as well."

However, as they became more experienced, both started to attach greater importance to i

5.7.5. Development of ideas

The last question of the interview was an attempt to find out about the development of experienced teachers' ideas and methods of teaching over time. Patton (1990) points out that it is easier for people to answer questions about the present than the past, since one's memory of the past is not always complete. So some teachers, such as T8, gave rather vague responses:

"I think it must have, because I've been teaching for so long - it must have."

However, others had clearer ideas. T7 responded:

> "I think when I first started / gosh when I first started I don't even want to think / I think I've forgotten, you know, it was a disaster. I've learnt, over the years, to make it real, that's what I've done."

Earlier T7 had responded to question 9 (about whether Newton III makes sense - see section 5.5, p 69) that

> "When I first came across it [Newton III], it didn't make sense to me at all"

The interviewer asked what had changed that and T7 responded:

> "I think trying to explain it to other people. You had to make it real. Take examples, work through the examples, with actual real life examples, and try to make sense out of it. Because I always learnt it as action-reaction, you know. I thought no no no, there must be a better way to put it down."

T4 said that her teaching had changed "drastically":

> "You kind of sort of feel things intuitively that you're not doing it correctly. ... So it was in discussion with [an experienced teacher] that we sort of thrashed it out and changed it and thrashed it out and then we said "No hang on, we've got to introduce it earlier."

She felt that seeing "the difficulties that the children got into, and trying to help them" had helped her change.

T1 saw the depth of her own understanding and her teaching as going hand-in-hand. When asked how her teaching had changed, she replied:

> "I think just in terms of the depth because I didn't have a very good understanding of it at all and even more than that, I didn't see it as particularly important, beforehand "

In response to the question of its importance she had stated:

> "I think it's one that I've overlooked easily and not been any worse for it - superficially. It's one that I've managed to go round without thinking that I've missed out on anything. ... I think now that it's one of the most useful laws in terms of understanding interaction between bodies."

T1's description of "overlooking" relates to the deceptive apparent simplicity of Newton III (section 5.5, p 69), as does T5's answer to whether his understanding had changed:

> " Yes most definitely. ... I think that you've got definite ideas of what it is, and I think once you start teaching you realise when you're doing problems that

maybe it's not as clear cut as you think it is."

T3 (who has three years of Std 10 teaching experience) gave the following insight:

> "Well I mean, in your first year it's all new to you - the physics you do at varsity is totally different to the physics you do here. Methodology doesn't really help much - so you're basically learning it once again as a matric pupil, in your first year. In your second year I suppose you decide [indistinct] now that you understand it, how can you make them understand it more."

What comes through strongly in the above quotes is that experience in teaching Newton III often has an effect for the good on the understanding and/or the teaching of the teacher. Most of the above teachers report some or other improvement in their understanding. Moreover, the experienced teachers were generally more confident in their answers. As for teaching methods, it seems experience can lead to a change in the form in which Newton III is stated (T7); change in when it is presented (T4); and change in the depth in which it is presented (T1). Thus the following hypothesis can be formulated:

H2: **Experience in teaching Newton III can result in improvement in the understanding and/or teaching methods of a teacher.**

In looking more broadly at all the interviewees in this study, the hypothesis bears up. The students who had no Std 10 teaching experience (S1, S2, S5, S6 and S7) did not demonstrate good understanding of Newton III: they applied it correctly to at most two of the four situations they were presented with. They also all gave Newton III in the incomplete form B. On the other hand, all of the teachers with 5 or more years of Std 10 teaching experience, apart from T5, applied Newton III correctly in every situation, and either gave form A or at least showed that they recognised that the incomplete form B is inferior.

5.8. SUMMARY

The interviewees were all able to explain the concept of force, but in discussion it became clear that some of them had non-Newtonian ideas about force. These correspond to the found through research with students: the idea that action and reaction can cancel, and the idea that bigger and faster bodies exert greater forces. T9 took this last idea a step further by relating it the equation $F = ma$.

Most interviewees could state Newton III, although the incomplete form B statement was the most popular form amongst the interviewees. The use of this form often correlated with faulty application of Newton III, as revealed by the IAI method. The IAI method helped to uncover other alternative ideas, such as the system confusion, and the "one force" idea. The IAI cards as well as later questions revealed confusion amongst some interviewees as to just what constitutes an action-reaction pair. However the results of the interviewees on the IAI cards were generally good compared to the results of research with students.

A number of the interviewees placed limitations on the universality of Newton III: claiming that it only applies to contact forces, or to pushes, or to stationary bodies. Even where people did not give limitations, they were hesitant as to the universality of Newton III.

Some interviewees felt comfortable with Newton III; some did not. What is interesting is that some of the interviewees who had not used Newton III in the IAI situations said that Newton III made sense to them. This points to the deceptive apparent simplicity of Newton III.

Experienced teachers had varied ideas on the teaching of Newton III. Some felt it should come sooner than Std 10, whilst others did not. Some expressed that their attitudes had been influenced by the external examinations, resulting in their not paying much attention to the law. Generally, more experience teaching Newton III seems to contribute both to understanding of the concept as well as to appreciation of its importance.

Overall, a number of alternative ideas were identified, some of which are found in the research literature and some of which are not, and two hypotheses were formulated. In fact it is possible to classify 75 % of the sample interviewed in terms of two types of interviewee. These two types are outlined in Table 11 (p 78); each is true of six interviewees. Both hypotheses apply to all of the interviewees listed in the table.

Table 11 : TWO TYPES OF INTERVIEWEE

TYPE	CHARACTERISTICS	EXAMPLES
TYPE 1	- Uses form A - Always applies Newton III correctly - Always uses "force" correctly - Gives a standard definition of force - Has Std 10 teaching experience	S3 S4 T1 T2 T6 T7
TYPE 2	- Uses the incomplete form B - Does not always apply Newton III correctly - Cannot apply Newton III to a tug of war (* T9 was not given the tug of war IAI) - Makes mistakes in use of term "force"	S1 S2 S5 S7 T5 T9*

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

The research succeeded in furnishing answers to the three research questions posed in chapter one (section 1.1, p 1). The Interviews-About-Instances (IAI) method proved useful in establishing whether the interviewees applied Newton III in particular situations, and, together with other questions, provided an in depth profile of each interviewee's understanding of Newton III. The interviews also provided insights into teachers perceptions about teaching Newton III. The textbook analysis showed how the treatment of Newton III in South African textbooks compares with that of British and American textbooks. The answers to each of the three questions are presented in turn in this chapter, after which recommendations based on these conclusions are made regarding teacher training, textbooks, and education department policy.

6.1. CONCLUSIONS

6.1.1. Teacher understanding of Newton III

The research reviewed in chapter two indicates that students often have a poor understanding of Newton III. In contrast most of the teachers interviewed in the current research demonstrated good understanding of the law, with the teachers-in-training faring slightly less well. Strong correlations emerged between understanding of Newton III and two factors: the form of statement of the law, and the teaching experience of the teacher. On the basis of these correlations, two hypotheses were formulated.

The two forms of statement of Newton III used by teachers were form A (If one body exerts a force on a second body, the second body exerts a force on the first which is equal in magnitude and opposite in direction) and the incomplete form B (For every action there is an equal and opposite reaction). The first hypothesis relates understanding to the form used:

H1: **A teacher or student teacher who gives Newton III in form A is more likely to apply it correctly to all situations than one who gives Newton III in the incomplete form B.**

The second hypothesis expresses the effect which Std 10 teaching experience can have on a teacher's understanding of Newton III:

H2: **Experience in teaching Newton III can result in improvement in the understanding and/or teaching methods of a teacher.**

Both of these hypotheses apply to the teachers who can be categorised by the two types in Table 11 (p 78).

Some of the interviewees held alternative ideas in their understanding of Newton III. Two alternative ideas not found in the research reviewed in Chapter 2 were uncovered. The first is the confusion surrounding the term "system": some people appear to confuse a "system of forces" (forces all acting on *one* body) and an "isolated system" (in which momentum is conserved; *two* or more bodies, with no external unbalanced forces acting on the system). This confusion may be part of the reason why some people think that an action-reaction pair cancel.

The second alternative idea is the "one force" idea, according to which an action-reaction pair consists of only one force. The reaction force is seen as the same force being "given back" in the opposite direction. Where two bodies actively exert forces on each other (as in a tug of war), two action-reaction pairs are identified. This understanding neatly compromises Newton III with intuitive understanding.

In addition, the main alternative ideas found by researchers who have looked at student ideas relating to Newton III were held by some of the teachers and teachers-in-training in this study. These are that action and reaction forces can cancel, and that bigger and faster bodies are more forceful, so can exert greater forces. Relating to the latter idea, the misinterpretation of the formula F = ma found by Jordaan (1993, described in section 2.3.2, p 12) was also evident with two of the interviewees - they interpreted F as the force which is exerted *by* a mass m with an acceleration a instead of as the resultant force exerted *on* a mass m producing an acceleration a.

Some interviewees made the mistake of talking about the weight of an object as the force which it exerts on the surface on which it rests. For one of the interviewees, the weight of the pen is the action which ultimately causes the reaction force of the desk on the pen. The causal link meant that this interviewee saw the two forces on the pen as an action-reaction pair.

A number of the interviewees placed limitations on the universality of Newton III. Some felt that it only applied to contact forces. Others made the distinction between pushing and pulling. Still others narrowed it down to only stationary bodies. Even those who had been completely confident about their answers to the IAIs were generally not sure about the universality of Newton III. It was found that too strong a connection between Newton III and conservation of momentum can lead to the impression that like the conservation of momentum, Newton III can only be applied to isolated systems.

6.1.2. Perceptions of teachers

As expressed in H1, the perceptions of teachers about the teaching of Newton III can be influenced by experience in teaching it. In fact some of the more experienced teachers felt this had definitely been the case for them.

Experienced Std 10 teachers were generally aware of the inferiority of stating Newton III in the incomplete form B. They emphasised the need to make it clear that there are two different bodies involved. These teachers also showed some understanding of which of the IAI situations students are likely to have greater difficulty with.

Some of the experienced teachers referred to the effect which the external matriculation examination had had on their teaching. They felt that the fact that Newton III was not examined much had influenced them considerably when they had started teaching. But they had come to appreciate its importance for the concept of force in the course of their teaching.

Feelings about the importance of Newton III differed considerably however. One of the teachers had found that it worked well to introduce Newton III in Std 7. Another felt that Newton's laws should be left out of school physics syllabi altogether. Perceptions as to whether Newton III "made sense" also differed. In fact someone who had applied Newton III confidently to the IAI situations was as likely to feel that it made sense, as was someone who had not used Newton III in the IAI situations.

6.1.3. Textbooks

Comparison of the ten South African, seven British and six American textbooks showed some definite trends in certain countries. There was also a clear trend towards more detailed explanations in more recent textbooks, reflecting more understanding of problems which students have with Newton III.

In terms of the positioning of Newton III, recent South African texts are identical to their British and American counterparts. Older South African texts place Newton III after momentum, in accordance with previous syllabi.

The form in which Newton III is stated should make it clear that there are two bodies involved, with the two forces each acting on a different body. American textbooks have always tended to state Newton III in such a way, and British textbooks have tended towards such forms in more recent years. On the other hand, nearly all of the South African textbooks examined use the unhelpful incomplete form B. On the score of choice of form of statement of the law, the modern British and American textbooks are superior to the modern South African textbooks.

The explanations provided by the various texts were analysed. The American texts provide the most detailed and most helpful explanations. The South African explanations are generally sound. However, unlike the American texts they do not make the point that not all equal and opposite pairs are Newton III pairs, and they use the terms "action" and "reaction" without pointing out that these are interchangeable. The older British texts contain no discussion of Newton III but the more recent texts do include brief explanations. Overall then, the American textbooks provide the best explanations, with the South African textbooks second in line.

Misleading and incorrect statements in the section on Newton III were identified. None were found in any of the American textbooks, and two of the British textbooks contain misleading and/or incorrect statements. In contrast most of the South African textbooks contain at least one incorrect statement in the section on Newton III. Clearly South African textbooks lag behind the others in terms of accuracy.

The examples with which the textbooks authors chose to illustrate Newton III were classified in terms of the types of forces involved. To give as broad a feel for Newton III as possible, textbooks should include different types of forces in both static and dynamic situations. However, most of the textbooks examined limit their examples to contact examples. Of the four which include forces acting over distances, three consider only gravitational forces, and only one (a South African text) includes electrical and magnetic forces. Overall the South African textbooks are the most generous with examples, although these tend to be rather similar - involving pushes between moving bodies.

The diagrams accompanying the examples were examined. There is generally a lack of consistency of style in representing forces. Furthermore, it is sometimes difficult to make out which body a force is illustrated as acting on. In fact, certain diagrams seem more likely to confuse than to help, particularly those used in some of the South African textbooks. So, for the majority of the textbooks examined, the diagrams used do not fulfil their potential in helping the reader to understand the application of Newton III.

Overall, the modern American textbooks come through as presenting the best treatment of Newton III, with the British textbooks presenting the least helpful treatment. The South African textbooks' treatment is closer to the American treatment than the British treatment. However, the otherwise sound treatment of Newton III in South African textbooks is too often undermined by errors.

6.1.4. Links between teachers' understanding and textbooks

Certainly similarities can be observed between teachers' responses, and the way in which Newton III is presented in South African textbooks. The most significant is the form of statement: South African textbooks use the incomplete form B, and this was the form in which the majority of both the teachers and the teachers-in-training stated the law. In fact one teacher referred to this form as the "recognised definition", despite the fact that the syllabus gives the law in form A.

Some links can also be found between the misleading/incorrect statement in textbooks, and alternative ideas held by some of the interviewees. All but one of the South African textbooks examined give only examples with two bodies in contact, which suggests that Newton III only applies to contact forces - five of the interviewees felt that Newton III only applies to contact forces. Two of the modern South African textbooks present the weight of a body as a force which that body exerts on the surface on which it rests - five of the interviewees made a similar error.

These similarities suggest that the textbooks may have influenced some of the teachers in the way they state the law and in some of the alternative ideas which they hold.

6.2. RECOMMENDATIONS

6.2.1. Teacher training

From the results outlined in section 6.1.1. it is clear that one cannot assume that a university or college education leaves a prospective teacher with a good grasp of Newton III. Science methodology lecturers should perhaps set about identifying their students' misconceptions about Newton III (and other areas of science), and then attempt to address these. For a start, students need to be made aware that the apparent simplicity of Newton III is in fact deceptive.

Given the hypothesis that experience in teaching can help in understanding Newton III, it is perhaps worth including some of the elements of teaching in preparing prospective teachers. Discussion of examples may prove more effective in providing the cognitive conflict necessary for conceptual change, than listening to a lecture. It is worth exploring the possibilities of more interactive learning.

Teachers-in-training should be encouraged to use form A, and to emphasise the difference between forces exerted *on* bodies and forces exerted *by* bodies. They should be encouraged to include examples with non-contact forces in their teaching, and to make clear and effective use of diagrams. They should also be equipped with an understanding of the typical misconceptions concerning Newton III which they are likely to find in their students - that action and reaction can cancel, and bigger, faster bodies exert greater forces. They should perhaps also be made aware of the "one force" interpretation of Newton III, although it is not known how widespread this idea is. They need to be aware of the confusion which can arise if the two different uses of the term "system" in physics are not distinguished between.

Of course, Newton III is only a small part of physics, and teachers should be prepared to teach every part of physics, so practically there may be insufficient time for treating every section in this sort of depth. However, given the importance of Newton III to the concept of force, it is perhaps worth devoting some extra time to this particular section.

6.2.2. Textbooks

South African textbook authors need to be encouraged to state Newton III in form A, which makes it clear that the action and reaction forces act on two different bodies. In emphasising this, it would be helpful to distinguish clearly between forces exerted *by* bodies and forces exerted *on* bodies. Textbook authors would also do well to point out that not all equal and opposite pairs are Newton III pairs. The confusion between the two uses of the term "system" should be pre-empted by explicitly differentiating between the two. Consideration should also be given to dealing explicitly with the treatment of strings as transmitters of forces, and the way in which inanimate objects can exert forces.

It is the researcher's experience that errors in South African textbooks are not peculiar to the section on Newton III. Clearly greater rigour with respect to accuracy in textbooks is in order. Textbook writers also need to be willing to submit their writing to scrutiny by a panel of experts. However it should be noted that textbook writers are often placed under unfair time pressure as new syllabi are generally published at most a year before implementation. This leads on to the next area where changes need to be implemented.

6.2.3. Education departments

The education departments need to engage in better forward planning in order to provide time for textbook authors to produce high quality textbooks. In planning the next syllabus, consideration should be given to introducing the concepts contained in Newton's laws earlier in the curriculum. However more research is needed to establish whether this is in fact a sound idea. Either way, to help students distinguish between forces exerted *on* bodies and forces exerted *by* bodies, it would be helpful to talk of a force as exerted *by* one body *on* another, from the first time forces are introduced.

The finding that teachers are influenced by the content of the external Std 10 examination suggests that examiners should test conceptual understanding of Newton III. The external Std 10 Physics examinations tend to have a quantitative emphasis - large portions comprise calculations. The fact that questions which explore understanding of Newton III are qualitative is possibly the reason why Newton III is often ignored in these examinations. Another reason may be that examiners are taken in by the apparent simplicity of Newton III and thus see no reason to examine whether students have in fact understood it.

APPENDIX 1 : INTERVIEW GUIDE

{Note: this is not prescriptive, but merely a guideline. The purpose of the interview is to find out the interviewee's understandings and perceptions - some questions may not be relevant, and other areas may require further probing to eliminate ambiguity.}

INTRODUCTION

- Thank you for agreeing to help.

- Have you chatted to anyone who has been interviewed?

- Assurance of confidentiality - explanation of purpose of tape recorder

- We want to find out teachers' ideas - not interested in "right" answers but rather in your ideas - what you think.
  etc.

- Take your time.

SECTION 1 - APPLICATION OF NEWTON III

1. What, in your understanding, is a force?

[Present first illustration]

2. Does [A] exert a force on [B]? [If there is uncertainty, probe further.]

3. Does [B] exert a force on [A]?

4. [If answers are both "yes":] How do (the sizes of) these forces compare?

[Present second and third illustrations, and repeat questions 2 - 4]

SECTION 2 - NEWTON III

5. What, in your opinion, is the best way of stating Newton's Third Law of motion?

6. [If necessary:] Explain what you understand this to mean.

7. [If section 1 was weak:] Can you give an example?

8. Does this law apply to any pair of bodies which interact, or are there some cases where it does not apply? [If interviewee feels there are limits, probe.]

9. Does this law make intuitive sense to you? / Are you comfortable with this law?

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4. [If answers are both "yes":] How do (the sizes of) these forces compare?

[Present second and third illustrations, and repeat questions 2 - 4]

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9. Does this law make intuitive sense to you? / Are you comfortable with this law?

SECTION 3 - PAIRS OF FORCES

[Present illustration of book resting on table]

10. Can you identify some of the forces acting in this situation?

11. Can you name an "action-reaction" pair/ Newton's third law pair?
11a. Would those two forces [from question 10] be an action-reaction/ Newton III pair?

SECTION 4

- IF SECTION 1 WEAK:

[Present first illustration again.]

12. Does Newton's third law apply here? [If "no" - probe why not.]

13. How does this fit in with what you told me earlier?
[Probe further to find epistemological commitment, as well as attempts to resolve the conflict between the law and "common sense".]

[Repeat with other illustrations.]

- OTHERWISE:

14. [Referring to illustrations:] Do you find any of these examples more difficult to understand? [Probe]

SECTION 5 - TEACHING OF NEWTON III

15. How important do you think this law is in teaching?

16. What examples do/would you use in teaching it?

17. [For experienced teachers:] Whereabouts in the syllabus do you think it should be taught?

18. [For experienced teachers:] Has your teaching of NIII changed/evolved?

CONCLUSION

Thanks etc.

Please don't talk to any others about this interview!

APPENDIX 2
EXTRACT ON LUG AND NEWTON III - T8

T8: This has always worried me a little bit. You know, people talking about for instance, centrifugal forces where indeed there's no centrifugal force - the centrifugal always being equal but opposite to the centripetal force. I always try to identify, number one, are there two bodies because if there's only one body, Newton 3 doesn't apply and I think this is where most people make a mistake talking Newton 3 glibly and they're discussing one body. So there must be two bodies - the one body must act upon the other and therefore the other one reacts upon the one. It doesn't matter whether they are static situations or dynamic situations, either. Now if you say to me where doesn't Newton 3 apply / Rephrase the question/ I mean give me the question again.

INTERVIEWER: Does it apply to any pair of bodies which interact or are there any exceptions?

T8: So you've got the pair of bodies - are there any exceptions? [pause] I don't really know. Could you give me an exception and I could see if I agree with you.

INTERVIEWER: Let me ask another question. Can we get a force acting on just one / a force acting where there's only one body involved?

T8: Oh [Pause]

INTERVIEWER: Just to extend what you were saying earlier.

T8: If Newton 3 has to apply do the two bodies have to be physically in contact with each other?

INTERVIEWER: No

T8: Because you see, Newton's Gravitational isn't Newton 3 - you've got two bodies and there's a mutual force of attraction, but I wouldn't call it Newton 3.

INTERVIEWER: All right.

T8: I've never thought of that before. There two bodies, there's a force, they're not necessarily in contact - the moon and the earth - there's a gravitational force between them it's not a Newton 3 situation.

INTERVIEWER: All right, why not?

T8: Is it? Why do I think they have to be in contact? Why, isn't it a Newton 3 situation? The earth acts on the moon and the moon acts on the earth. You see, I've got that classified very neatly as Newton's gravitational. And I haven't ever thought of applying Newton 3 to it.

INTERVIEWER: Alright, are there any other non-contact cases where you would see Newton's third law applying? Magnetic, electrical?

T8: [Pause, then slowly] Why not? Electrostatic charged bodies, you've got two bodies, there's a force of interaction, it's mutual, they're equal but opposite, always, it qualifies. Does it correctly qualify?

INTERVIEWER: Ja, ja.

T8: I've never thought of that before.

INTERVIEWER: Okay, great, so you've seen it solely in terms of contact forces.

T8: Mm, bad. [laughs] Yes definitely, I'd like to say definitely. There's no reason why there actually has to be contact. You see one always thinks of a horse pushing a cart, [indistinct], a rocket carrying its fuel ...

APPENDIX 3
EXTRACT ON PUSH/PULL DISTINCTION - S6

INTERVIEWER: Alright with the tug of war, that's a contact force.

S: [pause] OK, again that's the sort of push-pull distinction. In the case of the rollerskates you've got a push, in the case of the tug of war you've got a pull. The Newton 3 definitely in the case of the push the two objects moving away from each other same as the balloon leaving the ground at the point of leaving the ground. That would be two things moving away from each other. Again Newton 3 would apply there sort of like you know your aircraft with the rocket blaster acting against the object, the aircraft. But in the case of the tug of war [pause] well look the winning side A is exerting a force on side B and side B is exerting a force on side A so they are acting against each other but the fact that side A's winning means that the forces are not equal so I'd say possibly [pause] looks superficially that Newton 3 doesn't apply in this case. Or if it does it's at, you know, sort of things like hands on rope kind of situation [I points out there is no rope]...So Newton 3 would exist at the point of the hands' contact.

INTERVIEWER: How do you explain then that A manages to pull B across the line?

S: Because A is exerting a greater force against the ground than B is. Possibly less friction on side B.

REFERENCES

Aquino, E.P. (1994). A Teaching Model in Physics: Effects on Link Generation, Conceptual Change and Achievement. Unpublished doctoral thesis, University of the Philippines, Quezon City.

Arons, A.B. (1990). A Guide to Introductory Physics Teaching. New York: John Wiley.

Benumof, D. (1965). Concepts in Physics. New Jersey: Prentice-Hall.

Bowen, S.G. and Roberts, O.J. (1986). Physical Science for Standards 9 and 10. Johannesburg: Southern Bo. . Publishers.

Boyle, R.K. and Maloney, D.P. (1991). Effect of written text on usage of Newton's third law. Journal of Research in Science Teaching 28(2), 123-139.

Breithaupt, J. (1987). Understanding Physics for Advanced Level. London: Hutchinson.

Brink, B.du P. and Jones, R.C. (1987). Physical Science standard 10. Kenwyn: Juta.

Broster, P. and James, H. (1986). Successful Science 10. Cape Town: Oxford University Press.

Brown, D.E. (1989). Students' concept of force: the importance of understanding Newton's third law. Physics Education 24, 353-358.

Carrick, M. (1982). Physics. Surrey: Thomas Nelson.

Champagne, A.B., Klopfer, L.E. and Anderson, J.H. (1980). Factors influencing the learning of classical mechanics. American Journal of Physics, 48(12), 1074-1079.

Clement, J. (1982). Students' preconceptions in introductory mechanics. American Journal of Physics 50(1), 66-71.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. Journal of Research in Science Teaching, 30(10), 1241-1257.

Cohen, C.G.W. (1991). Help-u-Science Physics Study Guide. Settlers: Help-u-publishers.

Coleman, R. and Williams, J. (1982). Doing physics - physics activities for groups. The Physics Teacher, April, 252-253.

Dana, T.M., Perkins, R., Ledford, K. and St. Pierre, M. (1993). Science and Children, April, 28-31.

Duncan, T. (1982). Physics: A textbook for Advanced Level Students. London: John Murray.

Enderstein, G. (1993). Force. Imstus News 23, 7-11.

Ericsson, K.A. and Simon, H.A. (1980). Verbal reports as data. Psychological Review 87(3), 215-248.

Feynman, R.P., Leighton, R.B. and Sands, M. (1963). The Feynman Lectures of Physics. Massachusetts: Addison-Wesley.

Finegold, M. (1989). Rockets and space flight. Spectrum, May, 11-17. (Unit developed by the Israel Institute of Technology).

Franklin, A. (1976). Principle of inertia in the middle ages. American Journal of Physics 44(6), 529-545.

Giancoli, D.C. (1991). Physics: Principles with Applications. 3rd Ed. New Jersey: Prentice-Hall.

Gilbert, J.K. and Osborne, R.J. (1980). "I understand, but I don't get it": some problems of learning science. School Science Review 61, 664-674.

Gilbert, J.K., Watts, D.M. and Osborne, R.J. (1982). Students' conceptions of ideas in mechanics. Physics Education,17, 62-66.

Gordon, J.E. (1968). The New Science of Strong Materials. Harmondsworth: Penguin.

Gordon, W., Neser, G.O., Pienaar, H.N. and Walters, S.W. (1969). Basic Senior Physics and Chemistry. Cape Town: Maskew Miller.

Hall, T. (1980). Simply Physics. London: Edward Arnold.

Halliday, D., Resnick, R. and Walker, J. (1993). Fundamentals of Physics. 4th ed. New York: John Wiley.

Halloun, I.A. and Hestenes, D. (1985). Common sense concepts about motion. American Journal of Physics 53(11), 1056-1065.

Hellingman, C. (1989). Do forces have twin brothers? Physics Education 24, 36-40.

Hellingman, C. (1992). Newton's third law revisited. Physics Education 27, 112-115.

Helm, H. (1978). Misconceptions about physical concepts among South African pupils studying physical science. South African Journal of Science 74, 285-290.

Helm, H. (1981). Pedantry or desirable accuracy? - some issues in physics teaching. Spectrum, March, 13-17.

Horn, L., Brink, B.duP. and Jones, R.C. (1987). Physical Science in Action Standard 10. Kenwyn: Juta.

Horn, L., Brink, B.duP. and Jones, R.C. (1990). Study Guide to Physical Science, Standard 10. Kenwyn: Juta.

Ivowi, U.M.O. (1984). Misconceptions in physics amongst Nigerian secondary school students. Physics Education, 19, 279-285.

Jordaan, A.S. (1993a) Leerlinge se begryping van Newton se tweede wet. Proceedings of the Fifteenth National Convention on Mathematics and Natural Science Education, University of the Orange Free State, South Africa, 80-91.

Jordaan, A.S. (1993b) Pupils' understanding of Newton's third law. Paper presented at the International Conference on Science Education in Developing Countries, Jerusalem, Israel.

Kane, J.W. and Sternheim (1983). Physics. 2nd Ed. New York: John Wiley.

Keighley, H.J., McKim, F.R., Clark, A. and Harrison, M.J. (1986). Mastering Physics. 3rd Ed. London: Macmillan Education.

Kvale, S. (1988). The 1000-page question. Phenomenology and Pedagogy 6(2).

Maloney, D.P. (1984). Rule-governed approaches to physics - Newton's third law. Physics Education 19, 37-42.

Marais, J.P.J. and Jordaan, A.S. (1991). Technikonstudente se probleme met die identifiseering van kragte. Spectrum 29(1), 28-31.

Marion, J.B. and Hornyak, W.F. (1984). Principles of Physics. Philadelphia: Saunders College Publishing.

Marioni, C. (1989). Aspects of students' understanding in classroom settings (age 10-17): case study on motion and inertia. Physics Education 24, 273-277.

McClelland, J.A.G. (1985). Misconceptions in mechanics and how to avoid them. Physics Education 20, 159-162.

Miles, M.B. and Huberman, A.M. (1984). Qualitative Data Analysis. California: Sage.

Minstrell, J. (1982a). Conceptual development research in the natural setting of a secondary science classroom. In: Rowe M.B. Education in the 80's. Washington DC: National Education Association.

Minstrell J. (1982b). Explaining the "at rest" condition of an object. The Physics Teacher, January, 10-14.

Moolla, M. (1989). A survey of alternative frameworks by standard nine students at a senior college in Johannesburg when they had to work with concepts from the physical science syllabus. Unpublished MSc research report, University of the Witwatersrand, Johannesburg.

Müller, J.C., Müller, C.J., Dreckmeyer, M. and Dal Bianco, F.G. (1986). Physical Science in Action Std 10 HG/SG. Pretoria: de Jager Haum.

Mwakapenda, W.W.J. (1994) The effectiveness of an inservice workshop: A case study with standard 9 and 10 teachers from the Katlehong area, South Africa. Unpublished MSc research report, University of the Witwatersrand, Johannesburg.

Nelkon, M. and Parker, P. (1968). Advanced Level Physics. 2nd Ed. London: Heinemann Educational Books.

Nuffield (1966). Physics Teachers' Guide III. London: Longmans/Penguin.

Nuffield (1966). Physics Teachers' Guide IV. London: Longmans/Penguin.

Osborne, J. and Freeman, J. (1989). Teaching Physics: a guide for the non-specialist. Cambridge: University Press.

Osborne, R. (1984). Children's dynamics. The Physics Teacher, November, 504-508.

Patton, M.Q. (1990). Qualitative Evaluation and Research Methods. 2nd Ed. California: Sage.

Pienaar, H.N. and Walters, S.W. (1975). Senior Basic Physical Science 9. 2nd ed. Cape Town: Maskew Miller.

Pienaar, H.N., Walters, S.W., Schreuder, B.K. and de Jager, N. de B. (1987). Senior Physical Science 10. Cape Town: Maskew Miller Longman.

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 66(2), 211-227.

Prinsloo, L.A., Hattingh, C., Koen, J.G. and Spargo, P.E. (translator from Afrikaans) (1967). Physical Science for Seniors. Pretoria: Voortrekkerpers.

Roach, L.E. (1992). Demonstrating Newton's third law. The Science Teacher, December, 28-31.

Saayman, R. ed. (1988). Modular Teachers' Guide for the teaching of Physical Science. Stds 8 to 10 - Physics Guide (Vol 1). Stellenbosch: IMSTUS.

Sears, F.W., Zemansky, M.W. and Young, H.D. (1982). University Physics. 6th Ed. Massachusetts: Addison-Wesley.

Stinner, A. (1994). The story of force: from Aristotle to Einstein. Physics Education, 29, 77-85.

Talisayon, V.M. (1992). University students' alternative conceptions of force, motion and electric current. Proceedings of the International Conference on Physics Education (Karachi, Pakistan) 1991.

Terry, C. and Jones, G. (1986). Alternative frameworks: Newton's third law and conceptual change. European Journal of Science Education 8, 291-298.

Terry, C., Jones, G. and Hurford, W. (1985). Children's conceptual understanding of forces and equilibrium. Physics Education 20, 162-165.

Ueno, N. and Arimoto, N. (1993). Learning physics by expanding the metacontext of phenomena. The Quarterly Newsletter of the Laboratory of Comparative Human Cognition 15(2), 53-63.

Ueno, N., Arimoto, N. and Fujita, G. (1990). Conceptual Models and Points of View - Learning via making a new stage. Paper presented at AERA, Boston, April 1990.

Van Hise, Y.A. (1988). Student misconceptions in mechanics: an international problem? The Physics Teacher, November, 498-502.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1(2), 205-221.

Watts, D.M. (1983). A study of schoolchildren's alternative frameworks of the concept of force. European Journal of Science Education 5(2), 217-230.

Watts, D.M. and Gilbert, J.K. (1983). En' [illegible] in school science: students' conceptions for scientifically associated words. Research in [illegible]ce and Technological Education, (1), 161-171.

Whelan, P.M. and Hodgson, M.J. (1989). Essential Principles of Physics 2nd ed. London: John Murray.