LANGUAGE AS A CONFOUNDING VARIABLE; AN EXPLORATION INTO THE LINK BETWEEN LANGUAGE AND MISCONCEPTION

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Under the supervision of Professor Margaret Rutherford.

A research report submitted in part fulfilment of the requirements of the degree of Master of Science in Science Education at the University of the Witwatersrand.

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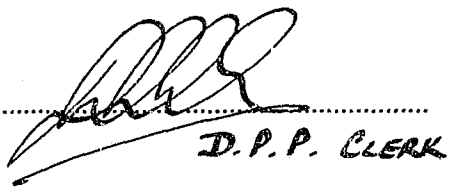
DECLARATION:

I declare that this research report is my own, unaided work. It is submitted in part fulfilment of the requirements for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.



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D. P. P. CLERK

.....21st..... day of .....OCTOBER..... 1998

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ABSTRACT

This study examines the possibility that language difficulties can be mistaken for misconception. A written test, consisting of twenty multiple choice items that had been used by other authors to diagnose misconceptions in physics was administered to a sample of matric level, English first language, South African students. A sub-sample of these subjects was then interviewed to explore the reasoning behind their choices. An analysis of the transcriptions of the recorded interviews revealed that in several cases, distractors were chosen by subjects who did not hold the target misconceptions the items were intended to diagnose, and that language problems, for example misinterpretation of the question text, were often the reasons behind the choices.

DEDICATION:

For my wife, Irene Anne Broekmann

and our children,

Sarah, Caitiin and Donovan

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CHAPTER 1: INTRODUCTION

1.1 PREAMBLE

The constructivist epistemology has given rise to valuable new ways of viewing and describing not only the nature of science but also how scientific concepts are learned.

Gilbert (1991) suggests a definition for science as "*a process of constructing predictive conceptual mo dels.*" (p 73) If this is so, then scientific knowledge must surely consist largely of such conceptual models. These models are constructed, as Hewson (1984) says, in response to an urge to make sense of experience. Hewson further says that "*people use the knowledge they* [already] *possess in their attempts to make sense of their experience*" and concludes that "*individuals from different backgrounds, having different experiences and knowing different things are likely to construct alternative conceptions from the same information.*" (p 16) It would seem however, to be equally possible that two individuals from the same background who have shared experiences may construct similar conceptions from the same information. Even so, their conceptions could appear to differ if their language competence is not equal. The degree to which an individual's utterances correspond with his or her thoughts must depend to some degree on that individual's language competence. Two people may thus appear to hold `alternative conceptions' rather because of their differing abilities to express themselves than because of any real differences between their mental models.

The notion that an individual's thoughts and language usage may not match is not without support. According to Osborne (1984), "*a child requires a `theory' about projectile motion if he or she is to successfully catch a ball, but it may be a theory he or she would be quite unconscious of and unable to articulate.*" (p 505) Shahn (1990) contends that although "*language generally develops at the same time as cognitive ability does ... its ability to deal with precision and nuance may not*

adequately reflect a person's ability to think and privately to deal with abstract concepts." (p 214)

If this is accepted, then it follows that language problems could perhaps be mistaken for conceptual problems and the broad aim of this study is to explore this possibility.

1.2 MOTIVATION

My initial motivation for the present study originates in 1987 when I was used as a subject for a study by Long (Bradley et al, 1990) in which a multiple choice questionnaire on chemical equilibrium was administered to student teachers and teachers of physical science. Subjects who answered questions incorrectly, by choosing distractors, were deemed to be holders of misconceptions.
When I later received feedback on the results of this study, two things became apparent to me: i) I had indeed answered some of the questions incorrectly but ii) some of my incorrect answers were not caused by misconceptions I may have held, but were rather the results of `maverick' interpretations of the question text. It seemed to me that the study had, in my case at least, yielded some `false positives'; i.e. my choice of distractors had in some cases originated in my use of language and did not constitute evidence of misconceptions.
This led me to wonder how many other subjects in this study, and perhaps in other similar studies, had revealed `phantom' misconceptions in the same way and it seemed to me that this could constitute a worthwhile topic for possible research.

1.3 CENTRAL TERMS

The precise meaning of `misconception' is central to this study and needs some discussion, as without a definition for the word, any findings of this study could generate fruitless debate as the notion of a `false positive' becomes problematic.

`Misconception' seems to be one of those words, like force or work, with a fairly broad spectrum of meanings, including both `everyday' and specialised meanings. It seems to be a word whose meaning `everyone knows' and yet I have encountered few who seem willing to try to pin down that meaning with any precision, leading me to doubt whether consensus as to its exact meaning exists, even among those using the word in science education.

A search for a good `official definition' has proved to be somewhat fruitless; in the first place, a familiar source proves to be of little value: The Shorter Oxford English Dictionary (1973) defines a concept as "*an idea of a class of objects, a general notion*" (p 388). The same source then defines a misconception as "*a notion resulting from misconceiving*" and misconceiving as "*to have a false conception or entertain wrong notions. To mistake the meaning of* [something]" (p 1333). A notion, in turn, is defined as "*A general concept under which a particular thing or person may be classed; a term expressive of such a concept*" (p 1417). Not only are these definitions circular, but I find them singularly unhelpful.

The related literature I have encountered has been no more helpful. Several authors, such as Bradley et al (1990), Ivowi (1984), Doran (1972) and Helm (1978 & 1980) have published papers reporting research into misconceptions in which they make no mention of any possible definition of the word, perhaps assuming that their readers will automatically share their (the authors') meaning. It is also apparent from context that the meaning of misconception differs from author to author, appearing for some to be a synonym for simply any error, and for others to be something more definite.

Other authors such as Peterson et al (1989) do attempt to define the term: "*misconception refers to students' ideas following instruction that are different from the acceptable and intended scientific viewpoint*" (p.301).

While this definition is better than none at all, I find it so broad and vague as to be

almost useless: what, precisely is meant by 'students' ideas', what is the 'acceptable and intended scientific viewpoint' and in what way are these to differ if the 'student's idea' is to deserve the title of 'misconception'?

Thus there is a need to establish a meaning for 'misconception' which will apply throughout this study and which could perhaps be adopted for more general use in science education. This meaning will be established in conjunction with the meaning for 'model'.

According to Johnson-Laird (1993), a model is a representation of some situation or phenomenon in the real world. If a situation or phenomenon consists of identifiable entities, each with its properties and with relationships between the entities; then a model consists of tokens representing the entities in the situation being modelled, with the properties of the tokens representing the properties of the entities, and a structure in which the relations among entities are represented by relations among their tokens. Jonhson - Laird uses 'token' not only to refer to symbols which can be written on paper or be part of a computer programme; the word can equally well refer to the components of a scale model and even to the concepts that are the components of our mental models. Our 'knowledge' can be thought of as the collection of models that we construct in the course of our lives to help us make sense of the world. This seems to be in agreement with Hewson and Hewson (1983), who state that "*a significant characteristic of a person's knowledge is its structure defined as the units of information as well as the ways in which they are linked together and used.*" (p.732)
The notion of a model as expressed above, may seem to some to be a bit simplistic; however it will suffice for the purposes of this study. It is also in agreement with the general definition of a model given in Gilbert (ed, 1997) that a model is a "*representation of an idea, object, event, process or system*" (p 2)

So much for 'model', now for 'misconception'.
As long as the structure of an individual's model corresponds with the structure of

the situation or phenomenon being modelled, in that the properties of the tokens correspond with the properties of the entities and the relations among the tokens correspond with the relations among the entities, no misconception can be said to exist. If however, either there is not a one-to-one correspondence between the entities and their tokens, or if the relations among the tokens do not correspond to the relations among the entities (or both) then that individual could be said to hold a misconception.

A misconception would not exist if the tokens were simply mis-labelled: for example somebody who knew very well that there was a force that tended to resist relative motion between two surfaces in contact, but who was not in the habit of calling that force `friction', might present the illusion that he or she held a misconception. For Johnson-Laird (1993) "*thinking is based on models rather than on expressions in a mental language.*" Scientific thinking, he says "*calls for procedures that can construct and manipulate models of phenomena rather than quasi-linguistic strings of symbols.*" (p 161) There is, he says a correspondence between the structure of a model and our conception of the phenomenon it represents and there need be no such correspondence where the syntactic structure of a linguistic representation of the same phenomenon is concerned.

It would thus be a mistake to assume that a misconception is held if the only evidence available is an individual's sloppy, inept or unorthodox language usage. A misconception can only exist if there is a `fault' in the structure of the model an individual has constructed: i.e. the structure of an individual's model differs from that of the concensus model generally accepted by the `mainstream' science community and as a possible consequence the predictions resulting from that individual's model could (but not necessarily will) differ from those yielded by the `mainstream' model.

Several terms have been coined as alternatives to `misconception'.

Behind the coining of these alternatives has been the notion that it is "*politically correct to accord to the childrens' ideas all the deference and respect that one would*

give to scientific theories" (Solomon, 1994; p 10) and that they are not to be regarded as `wrong' when they differ from those of the established scientific community. Included among these alternatives are such terms as `preconception', `naive conception', `alternative conception' and `alternative framework', which are popular currency among constructivists.

While the semantic differences between these alternative terms are subtle; the distinction between them and `misconception' is more deep-seated. The difference is not merely that the latter includes an element of judgement; the use of `misconception' in preference to the softer alternatives implies an epistemological position not strictly compatible with constructivism, i.e. realism.

`Misconception' has survived some strenuous attempts to discredit the term, as demonstrated by the fact that a conference title: `Misconceptions in Science and Mathematics' (Cornell University, Ithaca, NY) remained subsequently unchanged in spite of "*a rather heated rejection of the term*" (Solomon, 1994; p 9) in favour of some of the softer alternatives by some of the conference delegates. Perhaps this is an indication of the popularity of the realist position.

My own preference for `misconception' is based, apart from my epistemological leanings toward realism, on an objection to the notion that mainstream constructions which have survived rigorous testing can have a status equal to that of the naive ideas of children.

I shall thus be using the term throughout this study.

1.4 EPISTEMOLOGICAL POSITION

It may be useful at this point to attempt to clarify my own epistemological position: I prefer not to adopt any particular label but if one is necessary, then `quasi-constructivist with realist leanings' would perhaps suffice. While I recognize the usefulness of certain constructivist notions, I find others untenable. I accept the notion that knowledge is actively constructed by the learner and that the

construction process involves the production of viable explanations for our experiences. I also accept the notion that we interpret all incoming data in terms of our existing cognitive structures. I am at variance with `extreme' constructivism in that I do believe that learners seek to construct explanations that in some way reflect an ontological reality. I also fail to see that the fact that our knowledge of that reality cannot be unmediated in any way denies the possibility of its independent existence.

The idealist position that "*reality is the consequence rather than the cause of scientific construction*" (Matthews, 1994, p 142), is answered neatly, if somewhat bizarrely by Lawson (1993) who says that the possibility exists, as a logical consequence of this position that the real world is merely a mental construction, that the real world does not exist at all. He suggests that this could be tested, hypothesis-style, by standing in the path of a speeding automobile. If the car were merely a mental construction, it would be possible to survive the experience unharmed. I would be interested to meet the extreme constructivist who would be willing to put his epistemological position to the test in this manner. I, like Lawson, am too much of a realist to try it.

Another objection I have is to the `extreme' constructivist notion that the proper way to conduct research is independently of theoretical frameworks (Lawson, 1993). This, if we accept (and I do) the basic constructivist tenet that our perceptions of our incoming data are mediated by our existing constructions, is simply impossible. The extent to which I accept constructivism is illustrated by Driver and Oldham (1986): "*Although we may assume the existence of an external world we do not have direct access to it; science as public knowledge is not so much a discovery as a carefully checked construction.*" (p 109)

1.5 DIAGNOSIS OF MISCONCEPTIONS

To decide whether an individual holds a misconception or not, we would need to

examine the mental model he or she has constructed and compare it with that part of 'reality' it is meant to represent. This presents us with a serious problem as pointed out by Bodner (1990): only our own mental images are available to us for direct scrutiny; those of another individual are not and nor is 'reality' itself. How then can we make any kind of comparison? Although we have no direct access to any other individual's thoughts, we can make inferences from their utterances, actions and writings. But because we interpret these observable phenomena in terms of our own existing constructs just as we do any other part of the 'real' world, any conclusions we may draw are necessarily suspect. In addition to this, Clement (1979) referring to an analysis of a clinical interview, cautions against confusing verbal statements with thought patterns as meaning can be distorted in two places during communication; the first being the translation from thought to statement by the speaker/writer and the second being the translation from statement to thought by the listener/reader.

1.6 RATIONALE FOR THIS STUDY

Language competence varies among individuals, who range from the linguistically underdeveloped, to the linguistically well developed. Attitudes also vary: there are both careful language users and careless.
The accuracy with which the language used by an individual expresses that individual's thoughts must surely depend on the individual's degree of language competence and attitude to language usage.

It is thus possible that an individual's collection of mental models could correspond quite well with those accepted by the mainstream science community, despite that individual's inability to express scientific concepts accurately. In such an individual poor expression could be mistaken for misconception.

If this is true the possibility exists that written tests intended to diagnose misconceptions sometimes yield 'false positives', which result from language

problems and not from genuine misconceptions. It might also be possible that such tests sometimes yield 'false negatives', where misconceptions do indeed exist, but that language difficulties mask the fact.

My intention is thus to attempt to distinguish between genuine misconceptions (as I have defined them) and pseudo-misconceptions, i.e. 'false positives' arising from language sources rather than from faults in the mental model.

1.7 HYPOTHESIS

Poor language usage can be mistaken for misconception, with the result that written tests intended to diagnose misconceptions sometimes yield 'false positives', which result from language problems and not from genuine misconceptions.

The research instrument tested the null form of this hypothesis, namely:

Language plays no role as a confounding variable during the diagnosis of misconceptions using written tests.

1.8 SIGNIFICANCE

Ideally, a test designed to diagnose misconceptions should be capable of distinguishing between a positive result that arises from a genuine misconception and one arising from some other cause such as the use of language. Evidence supporting the hypothesis above (i.e. rejecting the null hypothesis), would tend to question the validity of a purely written or computer-based test because there would then be doubt that these tests possess any such capability.
The same limitation would of course also apply to the interview, but not to the same extent due to its greater flexibility; it would be safer to draw conclusions about a subject's cognitive structures on the basis of cross- questioning during an interview than simply on the basis of the subject's performance in a multiple choice test.

CHAPTER 2: LITERATURE REVIEW

2.1 PREAMBLE

In this chapter a selection of literature is discussed to illustrate briefly the current state of research into the problem at hand. The literature reviewed for this purpose is discussed under three headings: the first of these deals with language issues in relation to science education and the second with misconceptions, their identification and their remediation. In the third section some `near misses', involving some tentative bridging between the two issues, are discussed.

Nowhere in the literature was language given more than passing consideration as a possible confounding variable in the diagnosis of misconceptions.

2.2 LANGUAGE STUDIES

The main thrust of language studies has been the difficulties presented to the learner of science by the scientific register. Scientific authors, in striving for precision, often subject their readers "*to a large number of scientific terms, each with their own precise meaning outside familiar context clues, all embedded in an extremely complex sentence structure.*" (Bulman, 1986, p 21)
Studies in the area have typically dealt with difficulties arising from general grammatical complexity and readability of texts, coupled with difficulties involving vocabulary.

2.2.1 COMPLEXITY AND READABILITY

The complexity of some scientific concepts demands a degree of complexity in the language in which they are expressed. Scientific text is thus usually considerably

more complex than other text, a fact illustrated by the unusually great length of sentences in scientific text, which "*means that there is usually more than one clause and the introduction of subordinate clauses is generally associated with an increase in the difficulty of a text.*" (Bulman, 1986, p 22)

In addition to this, scientific text usually conforms to a stylistic tradition, supposedly "*required by objective truth*" (Strube, 1989, p 292) dating back to the 17 th century, commonly known as `formal'. This style is characterised, among other things, by a lack of motivational factors, such as the absence of a narrative and an impersonal style as well as heavy use of passive, nominalized and modal verb forms which tend to make it difficult for the reader. (Bulman, 1986)

The great complexity of scientific prose is attested to by Gardner (1978) who found the logical connectives that link phrases, clauses and sentences to each other, occur more frequently in scientific texts than in non-scientific texts.

Merzyn (1987) concludes from the results of an investigation assessing the linguistic complexity of science textbooks by means of the cloze technique (among others) that there is `*a general tendency for school science texts to be over-demanding on pupils' abilities.*' (p 483)

2.2.2 VOCABULARY

a) Subject Specific Words

Bulman (1986) identifies as problematic, scientific terms which "*have very precise meanings that embody large and complex concepts which the pupil may not fully grasp or feel confident in using* [and which] *are often polysyllabic, difficult to spell, and to pronounce.*" (p 21) Not only do these words often have meanings that are inherently difficult to understand but new vocabulary is presented to the student at a rate not encountered even in a second language course; "*pupils are introduced to between 2 and 6 new words during a foreign language lesson, compared with 8 new terms per physics lesson.*" (Merzyn, 1987, p 484)

b) Everyday Words with Subject Specific Meanings

Johnstone and Cassels (1978 a & b), Gilbert and Osborne (1980) and Ryan (1985) identify as a another source of trouble the words commonly used in everyday speech which are given a different, or more precise meaning in scientific discourse. These words are potentially an even greater source of trouble than the subject specific words because students often believe erroneously that they do understand them and are thus likely to misconstrue meanings when either reading text or listening to lectures. Being unaware that any problem exists, such students are unlikely to remedy the situation without an instructor's intervention.

c) Logical Connectives

Gardner (1980) identifies the logical connective as a particular source of difficulty with vocabulary. Logical connectives play a vital role in linking phrases, clauses and sentences to one another and thus conveying meaning. The main finding of Gardner's study is that the meanings of many of the logical connectives commonly used in scientific texts are poorly understood. This, coupled with the greater frequency of their use in scientific texts would mean that scientific writing is generally difficult to understand.

2.2.3 SECOND LANGUAGE ISSUES

Considerable attention has been focussed on the special problems faced by students of science whose first language is not English and on possible solutions to those problems.

Peer tutoring is advocated by Gonzales (1981) as a means of improving the English proficiency of second language speakers. He suggests that "*students can learn English and in a relatively short period of time if they are placed in a language-rich environment*" (p 21).

Seddon and Waweru (1987) investigated the transfer of scientific concepts from one language to another. Students were taught in one language and tested in another. Differences between the performances of the various experimental and control groups were found to be insignificant, from which these authors concluded that concept transfer is possible from language to language for bilingual students. What is not clear is whether these subjects were really thinking in the other language or were merely translating successfully from one to the other.

In a related study, Collison (1974) addressed concept formation in English and the 'vernacular', concluding that "*vernacular allow better conceptualization for their native speakers than the second language English.*" (p 457) Collison advocates further research to establish at what stage English should be introduced (if ever) as a second language and in particular as a language of instruction for the sciences.

The general picture presented by these research findings is that the scientific register is a source of considerable difficulty for many students of science. (This is true for both first and second language speakers, although members of the two groups tend to experience different difficulties.)
In spite of this, in none of the literature quoted is there any statement that this difficulty could perhaps extend to the realm of misconception diagnosis.

2.3 MISCONCEPTION STUDIES

Misconception studies can be divided loosely into two categories, the first comprising studies in which the primary aim was the diagnosis (or identification) of misconceptions using one or more of a variety of diagnostic tools. In the second type of study the main concern was the remediation of misconceptions and the diagnostic tool was more of a means towards an end, being used to assess the effectiveness of the remedial intervention.

2.3.1 DIAGNOSIS OF MISCONCEPTIONS

Methods used for the diagnosis of misconceptions have included written instruments, computer-based instruments and interviews. For example:

Peterson, Treagust and Garnett (1989) describe the development and administration of a written instrument for the diagnosis of misconceptions relating to covalent bonding and molecular shapes. Data from interviews, student drawn concept maps and free response questions were used in the production of the instrument, consisting of fifteen two-tiered multiple choice items.

Bradley et al. (1990) describe a study conducted in 1987 by an honours student in which a purely written, multiple choice test was used to diagnose misconceptions held by secondary teachers and student teachers about aspects of chemical equilibrium. It was concluded that the study had revealed misconceptions held by subjects in both categories. As one of their research subjects I am in a position to state that the rationale in the initial feedback given to the subjects was that the choice of a distractor was regarded by the authors as indicative of a misconception, no other explanation was suggested.

Gilbert & Osborne (1980) have reported on the use of 'interviews-about-instances' as a 'method for investigating student understanding of concepts. Although the authors do not stress the intention to use this method for diagnosis of misconceptions, the possibility that it could be used for this purpose is clearly implied.

Posner and Gertzog (1982) discuss both the strengths and weaknesses of the clinical interview as a research tool. Under strengths, they cite its flexibility and "*its ability to give a descriptive assessment of concept learning.*" (p 199) Under weaknesses, they caution that the interview and the interpretation of the transcript during analysis may both be influenced by the interviewer's theoretical bias.

A computer-based instrument was used by Browning and Lehman (1988) to identify student misconceptions in genetics. This article is interesting in that the authors abandon the term `misconception' quite early in the article and use in its place such terms as `area of difficulties'. Of the three main areas of difficulty noted, only one seems to be related to a possible misconception in genetics, the other two being poor procedural skills.

Zietsman and Hewson (1986) conducted a study in which a comparison was made of two diagnostic tests; one using an apparatus in conjunction with `short, unstructured interviews', the other being a computer simulation of the same experiment as that shown using apparatus. Also assessed was the effectiveness of a conceptual change-based remedial strategy. Results showed that there was `no difference in the way in which these students responded to the relative motion of real objects, and a microcomputer simulation of that motion'; the authors concluded thus that the computer simulations were "*credible representations of reality*" (p 27). The remedial strategy was found to produce "*significant conceptual change in students holding alternative conceptions*" (p 27).

In none of these studies is there evidence of any explicit consideration of the `noise' produced by the necessity of using language to identify ideas: Peterson et al (1989) took great care in the creation of their instrument but made no mention in their article of any attempt to distinguish between a wrong answer resulting from a genuine misconception and a wrong answer resulting from a misinterpretation of the question. Bradley et al. (1990) made no mention at all of the possible effects of language misuse, either on the part of the subjects or within the questions, on the outcome of the study.
Browning & Lehman's (1988) program did detect a language problem, namely, the confusion of the two terms `phenotype' and `genotype', which surely constitutes evidence of poor vocabulary rather than of a misconception according to my definition. The authors' comment however, was merely that it was a "*somewhat puzzling error*" (p 755). Although Zietsman & Hewson (1986) identified two subjects

who gave differing responses for the two methods of diagnosis, no mention was made in the article of the possible role of language in this outcome.

Of direct relevance to this study are papers reporting studies specifically intended to diagnose or identify misconceptions or `alternative' conceptions using multiple choice questionnaires. These papers; by Helm, H. (1978), Helm, H. (1980), Hestenes, D. and Wells, M. (1992), Hestenes, D., Wells, M. and Swackhammer, G. (1992), Ivowi, U.M.O. (1984), Jordaan, F. (1995) and Moolla, M., (1989), which were used as sources for multiple choice items for my own research instrument, had certain features in common. Helm (1978 & 1980), Ivowi (1984), Jordaan (1995) and Moolla (1989) reported studies, which like that of Bradley et al (1990), each used a multiple choice questionnaire, administered to reasonably large samples, to identify misconceptions or alternative conceptions supposedly held by their subjects. Hestenes et al (1992) present two collections of multiple choice items, each purported to be tools for the diagnosis of misconceptions. They provide also a "*Taxonomy of Misconceptions*" (p 144) comprising a list of misconceptions and for each, an indication of which distractor in which item identifies the misconception. In all of these studies the underlying assumption seems to be that the choice of a distractor indicates that the subject holds a misconception. Alternative explanations for the choice are not considered.

2.3.2 REMEDIATION OF MISCONCEPTIONS

The diagnosis of misconceptions has in many instances been an integral part of studies into their remediation, in the form of pre-tests and post-tests aimed at assessing the effectiveness of some interventional teaching strategy.
The main concern of these studies is the remedial strategy, the diagnostic tool being more of a means toward an end.

Hewson and Hewson (1983) used clinical interviews to identify `prior knowledge' for a study in which the effectiveness of an instructional strategy aimed at using students' prior knowledge to facilitate conceptual change was tested. However, the

pretest and post-test used to assess the conceptual change occurring in the experimental and control groups did not involve interviewing, simply a `pencil and paper' test which "*required students to indicate whether given statements were correct, incorrect or if they did not understand the statement.*" (p 734) Each of the items in the test provided the students with the opportunity to "*amplify their responses ..... [which] provided the tester with a richer understanding of the student response.*" (p 734)

One interesting feature of this study is that the authors apparently do not regard their `alternative conception' as synonymous with `misconception' as I have defined it; for example, for density, they list as an alternative conception `crowdedness'. While this certainly is not `the ratio of the mass per unit volume of a substance', which they give as the `scientific conception', it is also not `wrong'. One sample of a specific gas may be denser than another because it is more compressed; i.e. its molecules are more `crowded' than those of the other sample. A subject using `crowdedness' as a synonym for density may perhaps be criticised for using colloquial language but there may not necessarily be anything wrong with his or her mental model.

In a study investigating the relationship between `learning strategies' and cognitive change, BouJoaude (1992) found (perhaps un-surprisingly) that rote learners are less inclined to change their conceptual frameworks than "*relatively meaningful learners*" (p 687). `Meaningful learners' are those who "*create meaningful links*" (p 688) between new concepts and existing knowledge and in so doing "*may reduce memory overload and increase the amount of information they process simultaneously.*" (p 688) The degree to which `misunderstandings' were corrected by his subjects was assessed using a multiple choice test and language as a possible confounding variable was not considered in the study.

An investigation evaluating the effectiveness of an intervention, consisting of either a mixed language strategy or a conceptual change strategy for the remediation of

misconceptions held by primary school teacher trainees in Swaziland was carried out by Rollnick & Rutherford (1993). The `mixed language strategy' involved "*the use of English written materials with frequent use of mother tongue in explanations and discussion*". (p 371) The conceptual change strategy involved the use of `counter-explanations' in an attempt to make the "*scientific conception*" (p 370) for the demonstration where water is kept from falling out of an inverted glass by a piece of cardboard intelligible, plausible and fruitful. Findings were that the mixed language strategy was effective in the alleviation of misconceptions and that the conceptual change strategy was effective where English was the only language being used. The report advocates the mixed language strategy as a legitimate teaching tool where learners are multilingual. No mention was found of the possibility that language could be interfering in the instrument used to assess conceptual change.

2.4 SOME `NEAR MISSES'

Language deficiency did arise as a confounding variable in one of the diagnostic studies; but received little more than a passing mention. Hestenes et al (1992) report that during their validation process, sixteen subjects were interviewed. One of these, a Chinese "*exhibited a perfect understanding of all physical concepts in the Inventory* [but] *missed several questions because of a severe English deficiency*". (p 148) Also mentioned is that "*the most severe misconceptions were found in three Americans who clearly didn't understand Newton's Third Law and exhibited reading deficiencies to boot.*" (p 148) Inexplicably although ten out of the sixteen subjects interviewed (of which half were Americans, presumably first language speakers) "*exhibited moderate to severe difficulty understanding English text*" in which they mostly overlooked "*the critical role of `little words' such as prepositions in determining meaning*" (p 149), the authors were moved only to discard two rather obvious problem questions from their collection apparently thinking that they had thereby eliminated the problem. There was apparently no consideration of the possibility that all of their questions could perhaps be suspect to some degree.

The possible interference by language in student performance in test situations was investigated by Johnstone & Cassels (1978 a & b). In a study on a large sample of pre-O-level students test scores were greatly improved by minor changes in the wording of the test questions - such as changing negative statements in the question stem to positive statements. While this was not a misconception study, it does highlight the importance of language in its effect on performance in written tests.

Gilbert and Osborne (1980), already mentioned above, in their report on 'interviews about instances' show some affinity to my methodology, in that they claim the superiority of the interview over the paper and pencil test in "*obtaining information about student understanding*". (p 627) They do not, however make any claim to be diagnosing misconceptions nor do they make any explicit mention of language as a potential confounding variable.

Perhaps the closest approximation to the present study was found in a study by Yarroch (1991) in which the individual items in a multiple choice examination were assessed for validity. The 'item validity' here being distinct from the more familiar 'content' or 'face' validity in that it is quantitatively determined. It should also not be confused with the internal consistency usually associated with the statistical notion of validity. An item was regarded as having a high degree of validity if the number of times it was answered either correctly or incorrectly for the 'correct reason' greatly exceeded the number of times it was answered either correctly or incorrectly for the 'incorrect reason'. This study differs from mine in two important ways: firstly, the questions under scrutiny by Yarroch were not specifically designed to diagnose misconceptions and secondly, language was not cited as a possible 'incorrect reason'. It is, however, similar to mine in its motivation; as Yarroch says: "*An examination designed to measure behavioral skills should produce scores that directly reflect those skills or it is not accurate in its measurement*" (p 620). A diagnostic test supposedly designed to identify misconceptions but which identified language difficulties instead would similarly be inaccurate.

2.5 IN CONCLUSION

There is little evidence in the studies discussed above of any explicit consideration of the 'noise' produced by the necessity of using language to identify ideas; language as a confounding variable does not seem to have been seriously considered. There appears therefore to be no literature reporting research that matches the present study, i.e. an investigation into the possible interference of language in the diagnosis of misconceptions in first language speakers using multiple choice questions.

The history and current state of research into the present problem can therefore be summed up as follows: in spite of the fact that the difficulties presented by language are well documented and the diagnosis of misconceptions is now a well established research area, there has been and continues to be scant, if any, explicit consideration of the possibility that language acts as a confounding variable when attempts are made to diagnose misconceptions.

CHAPTER 3: RESEARCH DESIGN

3.1 OVERVIEW

The study was a qualitative exploration into the possibility that poor language usage can be mistaken for misconception. A written test consisting of multiple choice questions designed to diagnose commonly held misconceptions was constructed. The questions were selected from published studies where they had originally formed part of instruments specifically intended for the diagnosis of misconceptions. The test was administered to a sample of subjects and then a purposively selected sub-sample of these subjects was interviewed to establish the reasoning behind their responses to questions in the written test. A qualitative comparison between the responses to the written test and the interview data then made it possible to ascertain whether language problems had or had not interfered with the subjects' performance in the written test.

3.2 FIELD WORK LOCATIONS

3.2.1 THE PILOT SCHOOL

The pilot school was chosen primarily for its availability; I was a staff member there at the time of the study. In addition to this the majority of the students spoke English as their first language, the teachers were either first language speakers or else fluent second language speakers and English was the language of instruction. The school could in no way be regarded as `under-privileged' in the South African context, being what was then termed a `model C' or `state aided' school, i.e. a partially self-funding government school. The fact that the pilot school is monastic (all-male) meant that possible gender differences between subjects did not have to be considered.

3.2.2 THE MAIN STUDY SCHOOL

The school at which the main field work was done was chosen for its similarity to the pilot school. Both schools are situated in relatively well-to-do suburbs, serving socio-economically similar communities. Both schools are well equipped and staffed - at least by South African standards. The reason for choosing these schools was that if my (null) hypothesis could not be supported in these schools, it would be very likely that pupils in less well endowed schools would have even greater difficulties with language.

Both schools are monastic, catering only for boys, with English as the language of instruction.

The main study school differs from the pilot school in that it is a private school whereas the pilot school is a government school. Also the main study school is considerably smaller than the pilot school and there is less diversity among its students than is the case for the pilot school.

3.3 POPULATION AND SAMPLE

The target population was South African senior secondary science students whose first language is English.

The sample studied was drawn purposively from the population; its choice being determined partly by the availability of suitable subjects.

For the pilot, 108 senior science students and two staff members wrote the test; of these five were chosen to be interviewed, one of whom was a staff member.

For the main field work, 48 senior science students wrote the test and nine of these were chosen to be interviewed.

3.4 RATIONALE BEHIND THE CHOICE OF SUBJECTS

In both the pilot and the main study, conclusions were drawn only from the interview data. The students completing the written test were there simply to provide a pool from which to select suitable interview candidates. In both cases those writing the test needed to consist of science students, of at least senior secondary level. As my target interviewees English first language speakers for interview, there needed to be fairly large numbers of first language speakers among the written test sample. This was automatically the case at both pilot and main study schools.
In the pilot school, all senior students in science classes at a particular time on a particular day wrote the test. In the main study school, all senior science students excluding some absentees wrote the test.

The aim of the pilot was to conduct a trial run of both the written test and the interview process, with a view to 'debugging' them and establishing optimum procedures for the main study. In addition I wanted to establish the likelihood of obtaining a positive result. To this end, four students and one staff member were chosen to be interviewed, the students being selected to provide a range of performance levels and the staff member because it was suspected that he would be relatively free of misconceptions in the knowledge domain of the written test. The answer sheets were marked and one high performer, one low performer and two intermediate performers were chosen from among them. The staff member was selected because in spite of his qualifications (masters degree in physics) he answered three of the questions 'incorrectly'. With this sample it was possible to establish that: a) no changes to the written test were needed, b) what sort of questions were needed for the main interviews and c) the optimal manner of recording the interviews.

As the aim of the main study interviews was to test the hypothesis, the size of the interview sample was limited only by logistic considerations: nine was the largest

sample I was able to interview within the constraints of the situation. I had a little over a week in which to work and needed to minimise the disruption my activities were causing to the school programme. To achieve this I interviewed my subjects only during their regular science lessons and nine interviews was all the school timetable allowed during the time I was there.

The number of potential interviewees identified was actually in excess of the nine interviewed. On any one day it was thought necessary to have at least three possible candidates identified to cover the possibility that the chosen subject might for some reason be unavailable.

A subject was likely to be chosen if he had selected 'incorrect' answers to some of the questions in the written test, particularly in the case of questions where the source authors' choice of 'right answer was questionable; eg, items 1, 16, 17, 18 or 19. Also used was evidence of indecision; such as the choice of more than one answer or the cancellation of an initial choice and the substitution of another.

3.5 RATIONALE FOR CHOICE OF QUESTIONS

The development and construction of the research instrument is dealt with in detail in Chapter 4 and therefore only general comments will be made here, both in the case of the written test questions and the interview questions.

3.5.1 THE WRITTEN TEST

An item was suitable for the written test if it was a multiple choice question that had been used in published research that was aimed at misconception diagnosis. There also needed to be an element of interpretability in the question; i.e. there needed to be some aspect of the text in either the stem or the options or some aspect of an associated diagram that could be interpreted in a different way from that envisaged

by the author of the source article. It was this element of interpretability that would possibly lead my subjects to answer the item `incorrectly' without necessarily holding the misconception targeted by the item.

3.5.2 THE INTERVIEWS

Interview questions were aimed at establishing the reasoning behind the subjects' choices in the written test. The pilot interviews convinced me that it was not feasible to work with a fixed schedule where each subject was asked exactly the same questions as the variety of responses they gave demanded a more flexible approach. What was done instead was that during the marking of the answer sheets, potentially `interesting' subjects were identified (the rationale behind their choice was outlined in paragraph 3.4, on page 24) and for each of these, potentially interesting `lines of enquiry' were identified for selected items. Each line of enquiry began with a planned question and perhaps a few possible follow-up questions, the responses to which could not be anticipated and often demanded further enquiry, making it necessary to work `by ear' until the line of enquiry ceased to bear fruit. Thereafter another line of enquiry would be commenced in a similar manner with a new item. A line of enquiry would be terminated early if it seemed to be going nowhere or if it bore fruit relatively quickly, as the time allowed for each interview was quite limited - being in most cases little more than half an hour.

In each interview, questions that had been answered `correctly' were also probed, either to confirm that the answers were based on sound reasoning or to see whether any false negatives had perhaps occurred, i.e. correct answers based on or given in spite of misconceptions held by the subject.

As with the written test, details and some examples of actual questions used are given in Chapter 4.

3.6 RATIONALE BEHIND THE ANALYSIS

3.6.1 THE WRITTEN TEST

The written test and the analysis of the subjects' answer sheets were aimed primarily at identifying potential interview candidates. The choice of subjects for interview has been described above under paragraph 3.5.2.

3.6.2 THE INTERVIEWS

The analysis of the interview transcripts is also dealt with in Chapter 4. Suffice it to say here that the aim of analysing any interview transcript was to uncover the thought processes behind the answers given in the written test. It was hoped thereby to identify instances where language problems had interfered with the choice of answer.

CHAPTER 4: IMPLEMENTATION

4.1 DEVELOPMENT OF THE RESEARCH INSTRUMENT

4.1.1 PREPARATION

Papers were selected from the literature which reported studies in which multiple choice questionnaires had been used for the diagnosis of misconceptions. From these papers, questions were selected that were open to interpretation, and where a subject selecting a 'wrong' option need not necessarily hold a misconception. These questions were then examined by a panel of experts to establish face validity, i.e. to confirm that the intention behind the questions was to diagnose misconceptions and that they were open to interpretation. The twenty items deemed suitable made up the written test which was then administered, as part of a pilot, to a sample of the population at a South African secondary school.
A selection of these subjects was interviewed, the written test and interview data were examined to establish whether any further changes were necessary. The final test instrument, consisting of the written test and interview protocol was then constructed.

4.1.2 THE WRITTEN TEST

a) Criteria for choice of items

Selection of items for use in the written test was made according to the following rationale:
Firstly: the questions selected had all been used in published studies in which the stated intention was the diagnosis or identification of misconceptions or to 'identify subjects' ideas'.
Secondly: for each item, the possibility of misinterpretation by the subject existed. Possible reasons for misinterpretation could include any one or some combination of the following:

Difficulty; the linguistic complexity of the text could simply be beyond the competence of the subject.
Error; typographical, grammatical or semantic errors could exist, making interpretation of the question difficult for the subject.
Ambiguity; the meaning of some key word or phrase in the question could be open to interpretation, even if no actual error is involved. This is especially possible where words and phrases are used, whose 'everyday' meanings differ from their scientific meanings.

It is important also to note that even where there is no specific error in the question, misinterpretation is still possible for reasons inherent in the subject, for example:
Linguistic inadequacy; the language competence of the subject may not yet have reached the level of development required for successfully operating in the 'scientific register'.
Unconscious editing; people reading text sometimes gloss over errors or even correct them in their minds (for instance by inserting missing words) without being aware of doing so. Words (sometimes key words) in the text can also be unconsciously omitted by a reader. Either way, the subject's interpretation of a question could be influenced.

Thirdly: the format of the items needed to offer the subject little or no opportunity to clarify his or her answers. Multiple choice items fit this criterion particularly well
Finally: the knowledge domain chosen was Newtonian mechanics, at a level with which senior secondary science students, having received instruction, should be able to cope.

Items fitting the criteria presented above were found in the following sources:

Helm, H. (1978) Misconceptions about Physical Concepts among South African Pupils Studying Physical Science, South African Journal of Science, 74, 285 - 290.

Helm, H. (1980) Misconceptions in Physics amongst South African Students, Physics Education, (15), 92 - 97, 105.

Hestenes, D. and Wells, M. (1992) A Mechanics Baseline Test, The Physics Teacher, 30, 159 - 166.

Hestenes, D., Wells, M. and Swackhammer, G. (1992) Force Concept Inventory, The Physics Teacher, 30, 141 - 158

Ivowi, U.M.O. (1984) Misconceptions in Physics amongst Nigerian Secondary School Students, Physics Education, (19), 279 - 285.

Jordaan, F. (1995), Missing Links in Pupils' Understanding of Newton's Law of Gravitation. In Thorne, B. (Ed.) Proceedings of the Third Annual meeting of the South African Association of Teachers of Physical Science, pp 28 - 46.

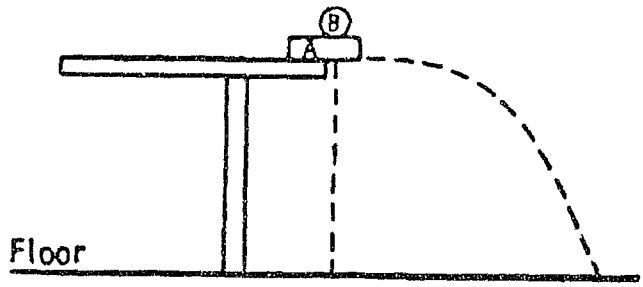
Moolla, M., (1989) A Survey of Alternative frameworks by Standard Nine Students at a Senior College in Johannesburg when they had to work with Concepts from the Physical Science Syllabus, A Research Report Submitted to the Faculty of Education, University of the Witwatersrand, Johannesburg for the Degree of Master of Education.

a) Discussion of items in written test

The 20 items which met the criteria discussed above are presented in this section and discussed to justify their inclusion in the written test. The full test as administered is given in Appendix 1.

ITEM # 1

The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

SOURCE: # 4 from: Ivowi (1984)

COMMENTS: The intention behind this item was to probe the subject's understanding of free fall and two dimensional projectile motion: "*The key concept here is that bodies projected horizontally fall freely under gravity.*" (Ivowi, 1984, p 280) The subject will presumably not choose the correct option (E) unless his or her conceptual model includes the notion that object A's initial horizontal velocity has no effect on its downward acceleration. A belief to the contrary would constitute a misconception as defined in this study. A careful examination of the question text and the diagram reveals several problems: The diagram is drawn showing object showing object B on top of and therefore (significantly) higher off the floor than object A. This means that Option D actually contains the correct prediction and the reason that accompanies it is only incorrect in that it is incomplete. Insertion of the word 'vertical' between 'shorter' and 'distance' would make option D entirely correct and it would not be unreasonable for the subject to imagine that it was intended to be there. The supposedly correct option (E) could only be correct if the two objects

had started falling from the same altitude and, as mentioned above, according to the diagram they don't. To choose this option, the subject would have to assume that the two objects had started from the same altitude, disregarding the evidence to the contrary in the diagram. Then, if option E is correct, why is option C not also correct? The argument given by the source author (Ivowi, 1984), that the given explanation is incomplete does not hold as none of the given explanations, including that in option E is complete. (Option E omits the word `vertical' between `initial' and `velocity' and fails to mention anything about the supposed equality of the vertical distance travelled.) Ivowi's claim (1984) that subjects choosing option C must have failed to take the objects' initial state of motion into account also does not hold. Although the option statement says nothing of the initial states of motion, the stem states that object B is `resting on' object A and as they are both depicted on the edge of a table there is no reason to suspect that their velocities prior to the `sharp push' are not zero.

ITEM #2

A large box is being pushed across the floor at a constant speed of 4.0 m/s.
What can you conclude about the forces acting on the box

A. If the force applied to the box is doubled, the speed of the box will increase to 8.0 m/s.
B. The amount of force applied to move the box at a constant speed must be more than its weight.
C. The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
D. The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
E There is a force being applied to the box to make it move but the external forces such as friction are not `real' forces they just resist motion.

SOURCE: #28 from: Hesteries, Wells & Swackhammer (1992)

COMMENTS: Option A can be interpreted as a correct statement: if the applied force is doubled, the box will accelerate and at some stage will reach a speed of 8 m/s and thereafter presumably continue accelerating. As there is no specification

in option A that this is not what was intended, it is a reasonable interpretation and choice of option A does not necessarily indicate the existence of the misconception in which speed (or velocity) and acceleration are supposedly confused, or that velocity is proportional to applied force. Option C is the 'officially' correct option, and it is failure to choose this option that most reliably indicates that the subject may hold the target misconception, which according to the source authors (Hestenes, Wells and Swackhammer, 1992), amounts to failure to understand Newton's first law. Option B could be chosen by a subject with some vague notion that heavier objects seem to have more friction than lighter objects on the same surface and who may not have fully grasped the vectorial nature of forces in general. Also present could be an 'adversarial' notion of opposing forces. Much of my comment on option B would also apply to option D; with the exception of the relationship between weight and friction. A choice of option E could indicate extensive deficiencies in the subject's understanding of the concept of friction, which could be another way of describing the misconception the source authors themselves identify for this option, i.e. "*Resistance opposes force*". (Hestenes, Wells and Swackhammer, 1992, p 144)

ITEM #3

If the force being applied to the box in the preceding problem (A large box is being pushed across the floor at a constant speed of 4.0 m/s.) is suddenly discontinued, the box will;

A. stop suddenly.
B. continue at a constant speed for a very short period of time and then slow to a stop.
C. immediately start slowing to a stop.
D. continue at a constant velocity.
E. increase speed for a very short period of time, then start slowing to a stop.

SOURCE: # 29 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: No specification is given regarding the mass of the box or the nature of the floor across which it is being pushed. For option C to be recognised as the

unequivocally correct choice, the subject would have to envisage a box with considerable inertia, moving with considerable speed across a reasonably slippery floor. Only one of these three conditions is specified in the question, the other two have to be assumed by the subject. A subject with a recent memory of pushing a light but large box across a carpeted floor may fail to realize that 4 m/s is a considerable speed (it is unlikely that any subject has personally experienced pushing a box at this speed!), and choose option A, not because he/she believes that a force is necessary to keep an object moving regardless of circumstances but simply as an accurate report of a past experience. Also what does the subject understand by 'suddenly'? A box on a carpet with deep pile would indeed stop 'suddenly' (provided 'suddenly' does not mean 'instantaneously') if its speed were not too high; i.e. the sort of speed at which one normally moves a box when pushing it across the floor. Option D may be chosen by a subject who assumes that the system is frictionless. Friction is so often omitted in the situations dealt with at school level that some subjects would regard this as the 'default' option and reason accordingly even where frictionless conditions have not been specified. Choice of option B could indicate a possible belief in some type of 'residual impetus' which dissipates. Option E could perhaps be chosen by a subject thinking that before discontinuing the force, one last push is given to make the box slide as far as possible, as is sometimes done by people moving boxes from place to place.

ITEM #4

A stone falling from the roof of a single story building to the surface of the earth;

A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
C. speeds up because of the constant gravitational force acting on it.
D. falls because of the intrinsic tendency of all objects to fall toward the earth.
E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

SOURCE: No. 17 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: Option A: a sufficiently small, light stone could fall in precisely this manner, even from such a low altitude as the top of a single storey building. There is no reason to assume that the subject will automatically interpret `stone' to mean one of considerable mass, and on which air resistance will have a negligible effect in the time during which it is falling. Further, it is possible that a subject may miss the significance of the altitude given as that of a `one storey building' or even fail to read the phrase altogether, and reason as if the stone had fallen from a much higher altitude.

Option B: the increase in gravitational force with decrease in altitude is so small in the course of a one storey fall as to be negligible and thus cannot be the primary cause of the stone's acceleration. A subject could omit the word `primary' when reading this option statement. Agreement with the statement may then simply indicate that he/she knows that freely falling objects accelerate in response to the force of gravity and that the force varies inversely with the square of r, neither of which constitutes evidence of a serious misconception.

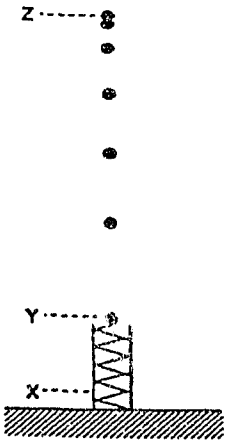
Option C, cited as the correct option, may be rejected by subjects not fully appreciating how small the increase in force is as r decreases.

Option D: choice of this option could well indicate the existence of an ancient misconception, however I doubt that any subjects would actually choose this option after instruction in Newtonian mechanics: even those agreeing with the statement would surely know that it flies in the face of convention and choose another option to hide their cognitive dissent.

Option E: could be accepted as correct by subjects believing that air pressure acts only downward and assists gravity in causing a falling body to accelerate; a genuine misconception.

ITEM # 5

* Refer to the diagram in the right margin to answer the following question.



The figure represents a multiflash photograph of a small steel ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, reaches its highest point at the point marked Z. '

Assuming that the air resistance was negligible;

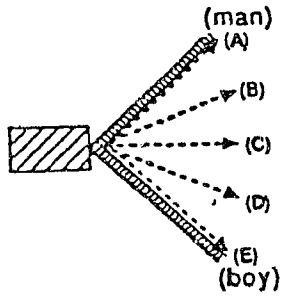
A. The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring)
B. The acceleration of the ball was decreasing on its way from point Y to point Z.
C. The acceleration of the ball was zero at point Z.
D. All of the above responses are correct.
E. The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

SOURCE: # 26 from: Hestenes & Wells (1992)

COMMENTS: Subjects who confuse velocity with acceleration could well be tempted to choose options A, B, C, or D. There is, however no way to tell whether such a subject actually believes that there is no distinction between the two concepts or whether the acceleration label has simply been (temporarily) attached to the velocity concept. Option A: The acceleration from point X to point Y would have to be greater in magnitude than g because the distance is smaller than from point Y to point Z. Thus the highest acceleration in the event occurs between points X and Y. This reasoning, combined with imperfect understanding of Hooke's Law, might lead a subject to choose this option as correct, even if there is no confusion between velocity and acceleration. Option E: The correct choice according to Newtonian reasoning.

ITEM # 6

Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as shown on the diagram to the right.
Which of the indicated paths (A - E) would most likely correspond to the path of the crate as they pull it along?



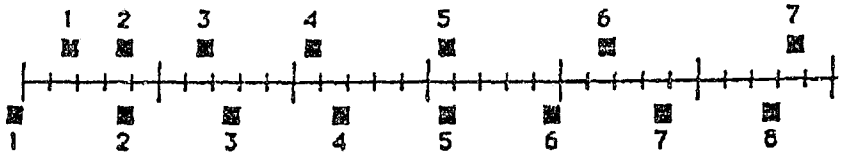
SOURCE: # 19 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: No indication is given in the question of the relative strengths of the man and the boy other than that the man is 'large'. The assumption is that the reader's interpretation will automatically be that the boy is small and therefore relatively weak and that for the man, 'large' must mean strong. This interpretation is by no means guaranteed. Some readers may envisage an athletic boy in his late teens who is as strong as or perhaps even stronger than the large (possibly fat) man. With this reasoning, the paths indicated in options C and D can be regarded, along with that in option B, as corresponding with the directions resulting from correct vector sums of the forces and not, as the authors suggest, as evidence of a misconception involving "*force compromise*". (Hestenes, Wells and Swackhammer, 1992, p 144.)

Another problem is that the question asks for the 'likely path' of the crate being pulled and describes the given options as 'indicated paths - it does not ask for the direction of the resultant force'. Although an object must accelerate in the direction of a resultant force, it is not necessary for its path to be in the same direction. An example of this is an object moving at a steady speed in a circular path - the acceleration is toward the centre of the circle; at right angles to the path. It is thus possible that a subject who correctly determines the direction of a resultant force using the superposition principle may nevertheless err in predicting the path followed by an object acted on by several forces. Choosing a distractor for this item does not constitute evidence of the target misconception.

ITEM #7

* The positions of two blocks at successive 0.02 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

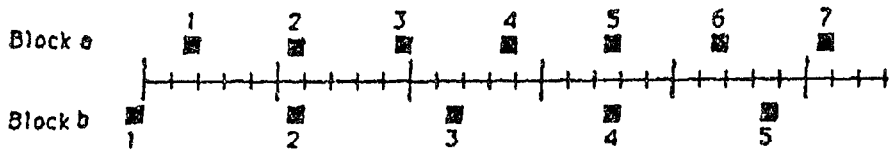
A. No.
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instant 2 and 5.
E Yes at some time during interval 3 to 4.

SOURCE: # 20 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: Choice of options B, C or D is taken by the source authors as evidence of lack of discrimination between the concepts of position and velocity. However, there seems to be no attempt at discriminating between the subject who genuinely believes that position and velocity are one and the same concept and one who simply uses position as evidence of velocity, but without confusing the two concepts. Choice of option A is regarded by the source authors as evidence of confusion between velocity and acceleration. My problem with this is that in my own experience, confusion between speed and acceleration is not as common as between velocity and acceleration, and the word used in the question is speed, not velocity. I also suspect that confusion between the words is more common than confusion between the concepts. Only an interview could establish whether a given subject was really failing to discriminate between two concepts or was simply confusing two words.

ITEM # 8

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



The acceleration of the blocks are related as follows:

A. acceleration of `a' > acceleration of `b'.
B. acceleration of `a' = acceleration `b' > 0.
C. acceleration of `b' > acceleration `a'.
D. acceleration of `b' = acceleration `a' = 0.
E. not enough information to answer.

SOURCE: # 21 from: Hestenes, Wells & Swackhammer (1992)

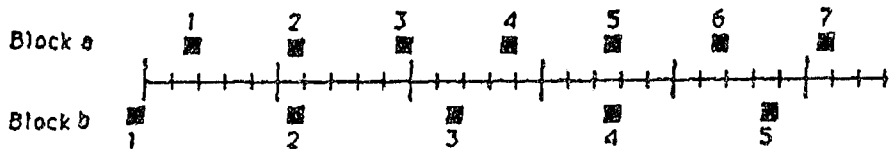
COMMENTS: Choice of option C is cited as evidence of lack of discrimination between acceleration and velocity. There is, however no way of distinguishing, other than by interview, between the subject who makes this choice because of a blending of the concepts, and one who makes this choice because of a confusion between the two words.

Although option A is not mentioned in the authors' taxonomy of misconceptions (Hestenes, Wells & Swackhammer, 1992), it is possible that a subject may choose it through a combination of careless reading and a lack of discrimination (for whatever reason) between acceleration and velocity.

Choice of option B is also cited as evidence that acceleration and velocity are un-discriminated; however it is possible that a subject may make this choice purely through careless reading.

ITEM # 8

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



The acceleration of the blocks are related as follows:

A. acceleration of `a' > acceleration of `b'.
B. acceleration of `a' = acceleration `b' > 0.
C. acceleration of `b' > acceleration `a'.
D. acceleration of `b' = acceleration `a' = 0.
E. not enough information to answer.

SOURCE: # 21 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: Choice of option C is cited as evidence of lack of discrimination between acceleration and velocity. There is, however no way of distinguishing, other than by interview, between the subject who makes this choice because of a blending of the concepts, and one who makes this choice because of a confusion between the two words.

Although option A is not mentioned in the authors' taxonomy of misconceptions (Hestenes, Wells & Swackhammer, 1992), it is possible that a subject may choose it through a combination of careless reading and a lack of discrimination (for whatever reason) between acceleration and velocity.

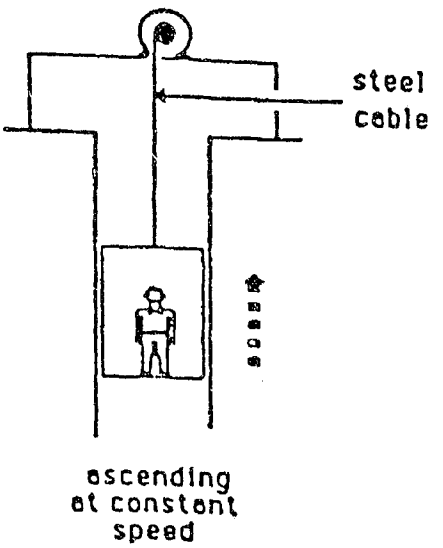
Choice of option B is also cited as evidence that acceleration and velocity are un-discriminated; however it is possible that a subject may make this choice purely through careless reading.

The two blocks do indeed have the same acceleration and if the `greater than' sign is overlooked by the subject, this option may seem correct, particularly if option D goes unread.

ITEM # 9

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;



A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

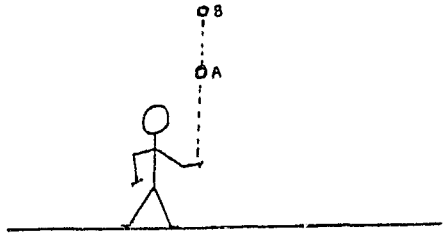
SOURCE: # 18 from: Hestenes, Wells & Swackhammer (1992)

COMMENTS: The main problem with this item is that no recognition is given to the possibility that velocity and acceleration may not be discriminated. Regardless of whether this involves a proper misconception or a simple confusion between the words, the fact remains that a subject may reason as if the lift had a constant upward acceleration rather than a constant upward velocity. Correct Newtonian

reasoning would thereafter lead the subject to choose option A as correct, which the authors cite as evidence of a misconception; i.e. that the 'largest force determines the motion'. Another potential source of confusion lies in the fact that the basic mechanism is the same for both air pressure and 'air friction'; i.e. collisions between air molecules and the surfaces of the object in question. Although unlikely, it is at least not inconceivable that a subject may find the statement that forces due to air resistance are so small as to be negligible and the later reference to air pressure as contradictory. Such a subject could ignore the earlier statement and regard the later statement as a reference to air 'friction'. A subject reasoning in this way, having also confused 'acceleration' with 'velocity' as argued above, could choose option E as correct, without necessarily holding any misconception.

ITEMS 10 &11

An object is thrown straight up into the air. It leaves the thrower's hand, goes up to B and then comes back down to the thrower's hand. [Assume that there is no friction involved]



10. While the object is moving upwards, the direction of the force on it is

    A. upwards.
    B. downwards.
    C. to the left.
    D. to the right.
    E. There is no force acting on it.

11. In the real world situation, which of the following statement/s is/are correct.

    A. When the object is moving upwards, friction acts downwards on it.
    B. When the object is moving downwards, friction acts upwards on it.
    C. The time taken by the object to go up would be longer.
    D. The maximum height reached by the object would be smaller.
    E. The object will take longer to come back to the thrower's hand.

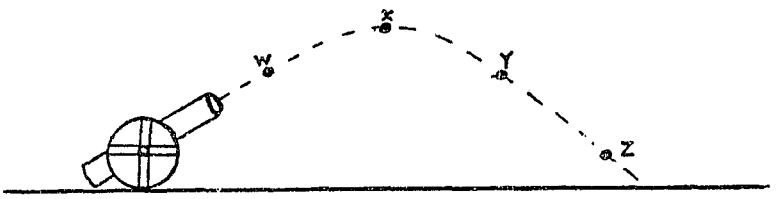
SOURCE: #'s 1 & 7 (respectively) from: Moolla (1989)

COMMENTS: It would appear that item # 10 is intended to reveal the use of pre-Newtonian reasoning in that the choice of option A may result from a subject's belief that a force is necessary to keep a body in motion even in the absence of friction. However, there is no indication in the text of the question as to precisely where the object is when the force mentioned in option A supposedly acts. A subject who interprets option A's 'upward force' as the force exerted on the object by the thrower's hand during the throwing action does not necessarily hold this misconception.

In item # 11 there is a typographical error: the question stem should have been negative as it was in the original, i.e: ... *which of the following statement/s is/are incorrect*? (Moolla, 1989, pp 16, 60). While this rather severely limits the item's usefulness in the present study, it is nevertheless worth discussing as its wording is problematic and the error does not render it un-answerable. No indication is given, for options C, D and E, as to what the 'real-world situation' is, or what it is being compared with. Although to be fair, there is only one reasonable possibility for option D, i.e. that the comparison is with the frictionless situation described in the preceding item, options C and E can be reasonably interpreted in another way: i.e. as alternatives to choose between, which could be confusing. Option C could be taken to mean that the object takes longer to go up than to come down and option E to mean that the object takes longer to come down than it did to go up. This interpretation may not so much lead the subject to make a 'wrong' choice on the basis of correct reasoning, as potentially prevent a subject without any significant misconceptions from making the correct choice, i.e. that all of the statements except C are correct, which in turn could lead the researcher to conclude incorrectly that the subject is the holder of a misconception. In view of the error no conclusions were based on any interviewee's response to this item.

ITEMS # 12 & 13

A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball.
[Assume that there is no friction involved.]



12. At which of the points mentioned in the diagram is the force on the cannon - ball the greatest?

    A. W
    B. X
    C. Y
    D. Z
    E. The force is the same at all four points.

13. At which of the points mentioned in the diagram is the effect of gravity the greatest?

    A. W
    B. X
    C. Y
    D. Z
    E. The effect of gravity is the same at all four points.

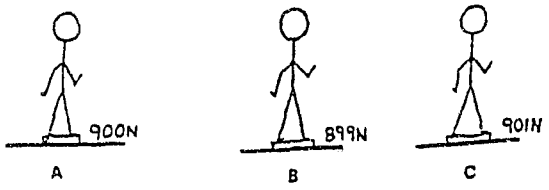
SOURCE: #'s 8 & 9 from: Moolla (1989)

COMMENTS: There is no indication as to the precise identity of the force referred to in item 12. A perfectly reasonable assumption is that since one is directed to ignore friction, the only force that now can be acting on the cannon ball is the force of gravity. This interpretation could then be confirmed by the reference in item 13 to the effect of gravity (rather than to the force of gravity); which could lead the subject to think that the 'effect' of gravity means the acceleration due to gravity, rather than the gravitational force. This interpretation would lead subjects to choose either

options D or E as correct for both items. Option D would be chosen by those who recognised that the force of gravity is stronger, (and the resulting acceleration higher), closer to the earth's surface. Option E would be chosen by those who recognised that the difference in altitude is so small that the differences in gravitational force and acceleration would be negligibly small. Although this interpretation would not result in the choice of one or other of the distractors (other than D), it is nevertheless one which was not considered by Moolla (1989). Whether the subject was working according to this interpretation, or that which Moolla (1989) regards as correct, could not emerge without the use of an interview.

ITEMS # 14 & 15

Three men of equal masses are each standing on stationary scales at different places on earth. The numbers represent their weight as shown by the scale.



14. Who experiences the greatest gravitational force?

A. A.
B. B.
C. C.
D. They all feel an equal gravitational force.
E. We cannot say because we need more data.

15 Who is closer to the earths centre?

A. A.
B. B.
C. C.
D. They are all the same distance from the earth's centre.
E. We cannot say because we need more data.

SOURCE: #'s 14 & 15 from: Moolla (1989)

COMMENTS: A subject may conceivably have a reasonably good understanding of Newton's law of gravitation but still be confused about the semantic relationships (or lack thereof) between `mass', `weight' and `the force of gravity'. If so, a subject's choice of option D as the answer to item 14 does not necessarily mean that an `alternative framework' is being used. Moolla's contention (1989) that subjects choosing this option are confusing gravitational force with gravitational acceleration is thus not the only possible explanation. Further, Moolla (1989) does not enlarge on what he means by `confuse'; i.e. whether the subject supposedly makes no mental distinction between the concepts, or simply makes a slip and mistakes one word another when reading the question. Also, subjects who had been taught that the gravitational acceleration of an object falling near the earth's surface is constant regardless of where it is measured could interpret `equal' (option D, item 14) and `the same' (option D, item 15) to mean respectively `almost equal' and `almost the same'. This would make option D a reasonable choice and not evidence of a misconception.

ITEMS # 16 & 17

The diagram shows an object hanging on a spring balance at sea level.

The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

    A. 30 N
    B. slightly more than 20 N
    C. exactly 20 N
    D. slightly less than 20 N
    E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

A. 30 N
B. greater than in Q 16 but less than 30 N
C. exactly 20 N
D. less than in Q 16 but greater than 10 N
E. 10 N

SOURCE: #'s 16 & 17 from: Moolla (1989)

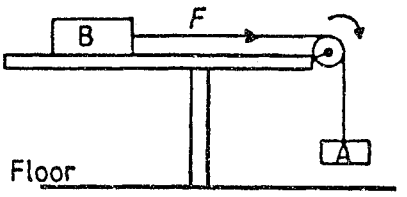
COMMENTS: In both items the question asks for the reading on the spring balance. On any spring balance that I have ever used, the readings at sea level and at an altitude of 50 metres would be the same, even though the object's weight would be slightly (negligibly) smaller 50 m above sea level. A subject selecting option C (for item 16) may not be demonstrating a misconception, but perhaps instead, extensive experience with spring balances. Moolla's conclusion (1989) that selection of this option indicates that a subject believes that "*weight, or the force of gravity does not depend on the distance from the earth's centre*" (p 21) may not be valid.

For item 17, even the 8800 m altitude of Mount Everest could not make Moolla's given answer (1989) of 10 N correct. 8800 m represents a 0,14% increase in distance from the earth's centre. This would result in such a small decrease in the weight of the object that it would be impossible to detect it with a standard spring-balance. The subject knowing this would be faced with a choice between options C and D, with the choice depending on the subject's individual interpretation of what is meant by 'slightly'.

ITEM # 18

In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by

A. Block A
B. The earth
C. The string
D. The table
E. The pulley



SOURCE: # 1 from: Helm (1978), Helm (1980) Also used in: Ivowi (1984)

COMMENTS: The meaning attached to the phrase 'is exerted by' plays a crucial role in the subjects' choice of answer in this item. According to the statistics supplied by both Helm (1978, 1980) and Ivowi (1984) in their reports, large numbers of subjects (not only high school pupils but also university students and teachers) chose options A or B rather than the correct option (C). The obvious fact that neither the earth nor block A is directly in contact with block B makes it difficult for me to accept that all of these subjects really believed that block A or the earth directly exerted the specified force F on block B. Surely at least some of these subjects were regarding block A or the earth as the origin of the force, which they then saw as being transferred to block B via the string. If I am correct in this then selection of options A or B could constitute evidence an alternative interpretation of the question and perhaps of sloppy reasoning rather, than of some misconception.

ITEM # 19

Which one of the following may not be a true statement about a body in uniform motion?

A. its velocity may be zero.
B. its velocity may be constant.
C. its acceleration may be zero.
D. its acceleration may be constant.
E. its velocity may be varying.

SOURCE: # 5 from: Ivowi (1984)

COMMENTS: This item seem to me to test the subjects' definitional accuracy rather than to probe the structures of their mental models and thus does not belong in an instrument designed to diagnose misconceptions. It was, however, included in an instrument for just that purpose and thus belongs in my instrument. Subjects to whom complete lack of motion does not represent any kind of motion at all may be tempted to select option A. If such a subject then reads no further, option E may be missed altogether. No misconception is necessary for a subject to follow the procedure outlined above, merely a failure to recognise that in the jargon of physics, zero velocity is a kind of motion, coupled with a careless answering procedure.

ITEM # 20

Which one of the following assertions concerning an astronaut standing on the moon, is true?

A. The astronaut experiences no force, because there is not an atmosphere.
B. The astronaut experiences no force, because only bodies near the earth are attracted by gravitation.
C. The astronaut only experiences a downward force as a result of the moon,s gravitational attraction.
D. The astronaut experiences a downward gravitational force and an upward force exerted by the moon's surface.
E. The astronaut only experiences an upward force exerted by the moon,s surface.

SOURCE: #5 from: Jordaan (1995)

COMMENTS: According to Jordaan (1995), the idea that the absence of air prevents the action of gravity is "*probably the most common of the alternative conceptions which pupils have*" (p 33). Subjects choosing option A may well hold this misconception but there is another possibility: the subject could regard the lack of an atmosphere as evidence of lack of gravity rather than as its cause. While I am not for a moment suggesting that such a subject holds no misconceptions at all, I do regard choice of this option as poor evidence that the subject really believes that air causes gravity or is in some way indispensable to it.

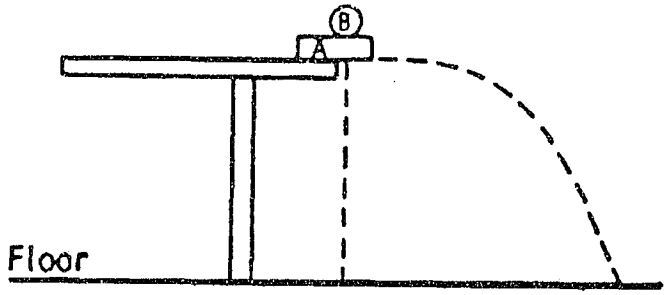
4.1.3 THE INTERVIEW PROTOCOL

The interviews, as already stated, were aimed at investigating the reasoning behind the choices of answer in the written test and whether and perhaps to what extent there was interference from language sources such as misinterpretation of the question text or the attachment of alternative meanings to key words. With this in mind, the interviewees were asked to explain verbally the reasoning behind their answers to selected questions in the written test.

As explained in the previous chapter, what was asked of the subjects during the interview was dependent not only on their responses to specific questions in the written test, but also to their responses to interview questions, which of course varied both from subject to subject and from question to question. For this reason, instead of a single, common, inflexible schedule of questions; for each item probed a line of enquiry was identified during the analysis of a subject's answer sheet. Each line began with one or more planned questions, aimed at establishing whether the answers given in the written test were supported by a scientifically acceptable or a discredited conceptual framework, and what role (if any) language had played in interfering with the subjects reasoning. These planned questions would be followed by unplanned questions as the interview developed and new insights arose. The examples that follow can be regarded as typical of the questions asked throughout the interview process.

ITEM #1:

The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

SOURCE: # 4 from: Ivowi (1984)

The interviewee had chosen Option D as the correct answer to this question, which would have been regarded by Ivowi (1984) as an incorrect answer; he was thus first asked to explain his reasoning:

"Alright [Name], *could you outline your reasoning behind your first answer, that's question .. the one about the two objects falling off the table."*

To this the subject replied that object A should reach the ground first, having the same acceleration as, but a shorter distance to travel than object B. This response prompted the following question:

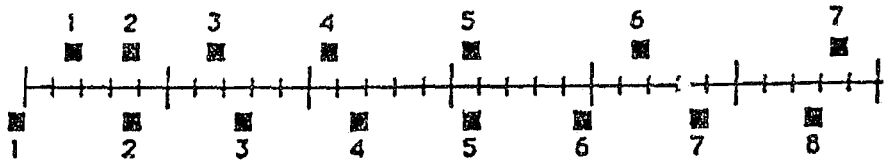
"Okay, now what about the fact that the diagram clearly shows A travelling a further distance?"

The interviewee's reply to this indicated that by 'shorter distance', he meant 'shorter vertical distance', thus completely justifying his answer as this is precisely what the item's diagram indicates, a fact which Ivowi (1984) seemed to ignore in his study. Both these questions were planned questions as I had anticipated the possibility that the interviewee was reasoning in this way. In other instances, interviewee's

replies to interview questions were unexpected, making it necessary for me to work 'off the cuff'. For an example of this another item will be used:

ITEM # 7

*The positions of two blocks at successive 0.02 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

A. No.
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instant 2 and 5.
E. Yes at some time during interval 3 to 4.

SOURCE: # 20 from: Hestenes, Wells and Swackhammer, (1992)

Subject 9 had changed his answer to this question, prompting me to ask:

"*Okay .. then .. number seven .. and in number seven, just confirm here, it looks as if you first chose E and then cancelled and changed to D.*"

To which he answered:

"Ja, that's what I did. //// Ja well, with this question .. the first .. set of blocks are obviously speeding up, .. and the second one's at constant .. and it starts off with a constant one .. er in the beginning it starts off with a constant one .. "

The incoherence of this reply forced me to abandon my intended line of enquiry and ask for clarification:

"*No hang on, what value is constant, though?*"

Which was followed by:

A: "*What value*?"

Q: "*Ja.*"

A: "*Well - one, two 'n three, .. four.*"

Q: "*No but is it speed, acceleration, .. what?*"

A: "*Oh .. velocity.*"

Which then allowed me to revert to my original line of questioning:

"*Right .. um ... yes, how do you know that .. the lower of the two blocks is .. at a constant velocity?*"

For other examples of interview questions - both planned and unplanned, the reader is referred to the interview transcripts included in Appendix 3 of this report.

4.2 IMPLEMENTATION

Two stages were involved in the practical implementation of the study, i.e. the pilot study and the main study.

4.2.1 THE PILOT STUDY

During the early part of 1995, The written test was administered to a sample of 108 subjects at the pilot school, which included matriculation students, standard nine students (i.e. grades twelve and eleven respectively) and three staff-members. Five of these pilot subjects, were selected to be interviewed on the basis of their performance in the written test . Two of the interviews were recorded on videotape. Another three were recorded on audiotape and transcribed. One of these transcriptions was subjected to detailed analysis.

4.2.2 THE MAIN STUDY

Once the pilot study had been completed, the main study was commenced at another school later in 1995. The written test was administered to a sample of 48 standard nine and matriculation students. (i.e. Grades eleven and twelve.) Nine of these subjects was selected to be interviewed on the basis of their performance in the written test.

The selected subjects were then interviewed and each interview was recorded on

audio tape. The interview tapes were transcribed and the transcriptions were analysed in order to establish, as far as possible, whether or not language had interfered in the subjects' reasoning while answering questions in the written test.

4.2.3 ANALYSIS

Interviewee discourse varied, consisting sometimes of clear, well articulated statements and at other times being incoherent and rambling where the interviewee was almost `thinking aloud'. The interview transcripts were carefully inspected to identify amid the discourse, statements that would give some indication of the interviewees' thought processes. In particular, statements were sought that:

* Either confirmed or rejected the original choice of option; and in the case of the latter, indicated new choices.
* Explained the reasoning behind the choice, whether a confirmed, original choice or a new choice; giving indication of the cognitive framework being used at the time.
* Indicated that the interviewee's interpretation of the question text differed from that of the original researcher. This could take the form of either explicit or implicit signs of language confusion, or else legitimate alternative interpretation.
* Indicated any influence that this language confusion might have had on the interviewee's reasoning.

Several `data categories' were identified during the analyses, which are listed and discussed in detail in the next chapter. A statement uttered in isolation was regarded as good evidence for a data category only if it was clear, unequivocal and uttered with confidence. Hesitant, poorly articulated statements were only regarded as good evidence if supported by other, corroborating statements and there was no contradiction from one statement in a series to the next.

The results of the analyses are presented in the next chapter. Descriptive statistics were also used to highlight interesting points and patterns in the data.

CHAPTER 5 : PRESENTATION AND ANALYSIS OF DATA

5.1 FROM THE PILOT STUDY

As stated before, the pilot study was carried out with three goals in mind:

Firstly: A final 'weeding out' of unsuitable items from the written test. However, none were identified and thus the test was left unchanged for the main field work.

Secondly: A trial run of the interview, with a view to 'de-bugging' and 'fine-tuning' the interview technique. Here two aspects were informative:

a) It was apparent that a fixed schedule of interview questions in which every interviewee was asked the same set of questions would not have allowed sufficient flexibility. Not only did the questions need to differ from interviewee to interviewee and from item to item, but I also found it necessary to vary and add to them during the course of the interview as new information and insights arose. Thus for each interviewee and for each item probed, a 'line of enquiry' was identified during the analysis of the answer sheet, beginning with one or more 'planned' questions and then usually progressing to working 'off the cuff'.

b) One idea that I had entertained during the planning stages was the possible use of a video camera to record the interviews. The idea was that in this way any gestures the interviewees might make would be conveniently recorded. It turned out however that such gestures, where meaningful, were not so frequent that the major inconvenience of transcribing from video was warranted. It was thus decided that audio tape would be the recording medium for the interviews.

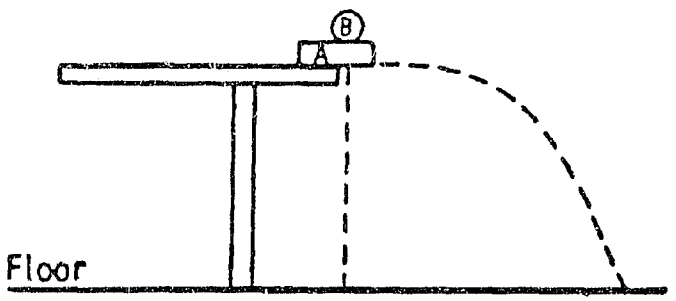
Thirdly: The one pilot interview transcript that was fully analyzed revealed that there was a good chance of obtaining positive results for this study; the analysis of this interview is discussed below:

5.2 ANALYSIS OF PILOT INTERVIEW

The interviewee chosen for analysis was a staff member, teaching mathematics at the junior secondary level in the pilot school. This interviewee was chosen because as a holder of a master's degree in material physics, it was felt he would be less likely than any of the other available interviewees to hold misconceptions about Newtonian physics and thus any 'incorrect' answers from this interviewee would be likely to have originated from other causes. This interviewee was asked to explain the reasoning behind his answers to each of four items in the questionnaire, three which the original authors would have rated as incorrect and thus indicative of misconceptions, and one which they would have rated as correct. His answers to the interview questions revealed that for each of the four items he held no misconception whatsoever and that for the three that would have been rated as incorrect by the original authors, his choice of answer was in each case based on an interpretation of the question text, not intended by the original author.

In ITEM 1 the interviewee chose option D, which the original author (Ivowi, 1984) would have regarded as incorrect although omitting to specify what misconception a choice of this option indicates.

1. The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

SOURCE: # 4 from: Ivowi, U.M.O. (1984)

The interviewee's explanation for his choice began with an indication that his reasoning was based on the fact that the diagram shows the two objects at differing heights:

" .. *well the two objects are at different heights, so they'll take er, different times to reach the floor* ..."

He then showed that he was fully aware of the independence of vertical and horizontal components in free fall:

"*The vertical distance is covered .. they both covered it in the same time .. the horizontal distance is covered in the same time .. ah well concurrently*, .."

and later:

".. *the object will stop moving once the .. as it were, it's used up it .. its height, that it has available to it to fall, and how far it moves horizontally in that time is irrelevant.*"

His use of the word `vertical' during his interview makes it possible that he also inserted the word when he originally answered the item in the written test. This would constitute editing the question text which would give it a meaning perhaps not intended by Ivowi (1984); hence a language origin for what is quite clearly a `false positive'.

In ITEM 3, the choice was option A, which would have been taken by the original author, as indicative of a misconception termed `active force; velocity proportional to applied force' (Hestenes et al 1992).

3. If the force being applied to the box in the preceding problem (A large box is being pushed across the floor at a constant speed of 4.0 m/s.) is suddenly discontinued, the box will;

A. stop suddenly.
B. continue at a constant speed for a very short period of time and then slow to a stop.
C. immediately start slowing to a stop.
D. continue at a constant velocity.
E. increase speed for a very short period of time, then start slowing to a stop.

SOURCE: # 29 from: Hestenes et al. (1992)

No evidence for the target misconception (see above) was forthcoming in the interview. Rather, the interviewee gave every indication that he was using Newtonian reasoning in support of his choice of a description of a familiar event:

"*.. I would assume that once the- the force is actually .. stopped moving and there's no friction to counteract it .. then the object would continue to move .. but even on an ice situation .. there would still be some amount of friction and even as soon as the force is not applied any more, // then the box would decelerate from its velocity to zero .. but over a sh.. over a longer time interval than if it were being pushed on a floor.*"

As long as the force of friction between the floor and the box described in the question stem is fairly high, such a box does stop so soon after the pushing force is discontinued that it can be said to stop virtually immediately. The lack of specification in the description of the situation in the question stem gives the interviewee such great interpretational freedom that choice of this option cannot be evidence of the target misconception if supported by Newtonian reasoning. Here then, is another false positive of language origin.

ITEM 19 presents a problem; it was used by the original author (Ivowi, 1984) in a study intended to identify misconceptions and yet if my definition of 'misconception' is used, this item does not test for a misconception at all: it merely probes the interviewee's knowledge of the definition of a term.

19. Which one of the following may not be a true statement about a body in uniform motion?

A. its velocity may be zero.
B. its velocity may be constant.
C. its acceleration may be zero.
D. its acceleration may be constant.
E. its velocity may be varying.

SOURCE: # 5 from: Ivowi (1984)

The item is nevertheless worth discussing here as it was answered `incorrectly' by this interviewee and his choice of option D is very definitely a false positive of language origin. Firstly the interviewee began his explanation of his choice of Option D by demonstrating beyond doubt that he agreed with the original author's definition of uniform motion and that he therefore did not hold the target `misconception':

"Uniform motion as I understand it is constant velocity".

He followed this up by justifying his choice of an incorrect option on the basis of a maverick but reasonable interpretation of the option statement of his choice, i.e. if the acceleration is constant, the velocity is varying and the body is not in `uniform motion'. This therefore `may not be a true statement about a body in uniform motion'. In fact it would only be a true statement if the `constant acceleration' were zero and he ruled out this possibility:

[from] *"the context of the question it seems that they don't mean 'constant' to mean zero as well ..".*

He demonstrated uncertainty of the precise intention behind the original researcher's use of phrases such as `may be' in the option statements and `may not be' in the question stem, actually stating that he was confused by the phrasing in the question and that he found the wording difficult to interpret:

"I must admit the wording of the question is strange; `may be' er I don't understand th .. they seem to imply that the velocity 'may' be constant, it could also be a number of other things..."

Having thus established with this interviewee that false positives of language origin can be demonstrated by the interview process, I felt confident to proceed with the main study.

5.3 THE MAIN STUDY

The written test was administered to the 48 matric (grade 12) and standard nine (grade 11) science students at a school in Gauteng. Nine of these subjects were then interviewed to establish, as far as possible, the reasoning behind some of their answers to the written test. The recordings of these interviews were then transcribed and analysed. The results obtained from these analyses are described below and then summarized in Table 1:

5.3.1 DATA CATEGORIES FROM INTERVIEW ANALYSES

The following categories of data each emerged at least once during the course of the interview process:

a) **FALSE POSITIVE**; the option was chosen for a reason other than that the interviewee holds the target misconception for the item. **[code: FP]**

b) **UN-TARGETED MISCONCEPTION**; a genuine misconception has been identified during the interview, but not the one targeted by the item under consideration. **[code: UM]**

c) **TRUE (or TARGET) MISCONCEPTION**; the interviewee presents good evidence that he holds the target misconception in both the written component and his responses to questions in the interview. **[code: TM]**

d) **POSSIBLE MISCONCEPTION**; the interviewee presents evidence of a misconception, but not conclusive. **[code: PM]**

e) **FALSE NEGATIVE**; the interviewee's answer to the written component suggests that he does not hold the target misconception but it emerges during the interview that he does. **[code: FN]**

f) **NO MISCONCEPTION**; both the written response and the interview reveal evidence of good reasoning. **[code: NM]**

g) **LANGUAGE CONFUSION**; interviewee presents evidence (unstated) of poor or confusing language usage. **[code: LC]**

h) **STATED LANGUAGE DIFFICULTY**; interviewee states that he had difficulty interpreting the question text. **[code: SLD]**

i) **NO CONCLUSION**; no definite conclusion could be drawn from the interviewee's answers to the interview questions. **[code: NC]**

j) **LANGUAGE ORIGIN** (a qualifier): the option was chosen because of the interviewee's failure to interpret the question text in the way envisaged by the original researcher. This could be due either to ambiguities in the question text or to the interviewee's own language abilities. **[code: LO]**

k) **UNKNOWN ORIGIN** (a qualifier): the interviewee presents no evidence for any specific reason for a given response. **[code: UO]**

5.4 SUMMARY OF RESULTS

TABLE 1: DATA CATEGORIES, INTERVIEWEES AND ITEMS

	1	2	3	4	5	6	7	8	9
1		NC	TM	FP/ LO &UM	TM	PM?/ NC	TM	FP/ LO	
2					TM	FN			TM
3					TM			NM	FP?
4	UM?	LC/ NC		TM	NM/ UM?			TM?/LC	
5		NC		TM?/ FP/ LO?	NC	TM?	NC// FP/ LO?		FP?
6							FP/ LO	FP/ LO	
7		LC/ PM	NM	FP/ LO	NM	NM	NM	NM	FP /UO
8		FP/ LO	FP/ LO	FP/ LO	NM	NM LC	NM	FP/ LO? LC	TM?
9	UM	TM /PM SLD	TM/ LC		NC/ LC + UM	TM		NC/ LC	TM + LC
10		NM	UM	NM?		NM			FP
11			NC/ SLD?						NC
12	FP/ LO	SLD/ FP/ LO	TM1 TM2	NM	TM	TM + UM	FP/ LO + UM		TM?
13		NC/ UM?	NM/ UM?	NC	UM	NM	TM		FP/ UM
14				NM				FP?/ NC	FP/ UO
15								NM	FP/ UO
16		FP/ UM1/ UM2?	NM UM?	TM	FP/ LO + UM	NM	FP/ UO NM	FP/ LO	FP/ UO
17		FP/ UM1	TM	TM	UM		FP/ LO UM	FP/ LO	FP/ UO LC
18	FP/ LO	FP/ LO	FP/ LO	FP/ LO	FP/ LO?	NM	FP/ LO	FP/ LO	FP LO
19	SLD	LC	LC- TM	TM? LC		FP/LOLC	NM LC	TM? NC	TM?
20		TM	TM & UM	TM	TM?/ UM	NM	UM	UM + LC	FP/ UO

INTERPRETATION OF TABLE 1:

The numbers at the tops of the columns are interviewee numbers, the numbers at the beginnings of the rows are question (item) numbers.

A question mark following a code indicates a degree of uncertainty:

Example 1: 'FP/LO?' (interviewee 8, question 8) means that the interviewee exhibited a false positive that could be attributed to language interference but not with certainty.

Example 2: 'NM/UM?' (interviewee 3, question 13) means that the interviewee answered the question correctly, confirmed during the interview that he did not hold the target misconception but then presented evidence suggestive of an un-targeted misconception.

Some of the results presented in table 1 above are further summarised below:

TABLE 2: DESCRIPTIVE STATISTICS

Number of items in which data category is demonstrated	Data category.					
	FP	FP/L	UM	TM	NM	FN
Total number.	42	28	21	29	22	1
Average number per interviewee.	4.7	3.1	2.3	3.2	2.4	0.1
Lowest number per interviewee.	1	1	1	0	0	0
Highest number per interviewee.	11	6	6	7	7	1
Average number per interviewee as a % of the number of items.	23.5	15.5	11.5	16	12	0.5

5.4.1 DISCUSSION OF DATA CATEGORIES

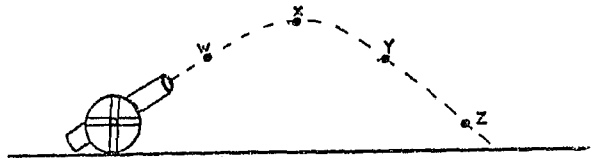
a) FALSE POSITIVES

A interviewee was deemed to have exhibited a false positive if, having chosen an option indicative of a misconception in the written test, his responses to the interview questions revealed that he did not in fact hold the target misconception for the item and that his choice of option was for some other reason, such as a misinterpretation of the question text. Every interviewee exhibited at least one definite false positive and most exhibited several. The false positives could be divided into two basic categories: Those which could be linked to language problems and those that could not.

i) FALSE POSITIVES LINKED TO LANGUAGE PROBLEMS

EXAMPLE 1: Interviewee 1, ITEM 12

12. A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball. [Assume that there is no friction involved.]



At which of the points mentioned in the diagram is the force on the cannon-ball the greatest?

A. W
B. X
C. Y
D. Z
E. The force is the same at all four points.

SOURCE: # 8 from: Moolla, M., (1989)

Interviewee 1 initially chose option E, aware that the variation in the gravitational force along the trajectory would be negligible, but he then:

"*decided to be sort of really sort of .. er nit picking about it and so I went for the .. the answer which I thought would be most accurate even if the difference between the sort of .. force at the .. at the points would be so slight .. "*

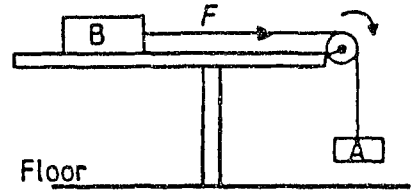
.. and changed his choice to option D.

Mcolla would have taken the choice of option D as evidence of the interviewee's belief that the velocity of a moving object is proportional to the applied force. During the interview however, Interviewee 1 showed no evidence of this belief at all; instead he linked the strength of the gravitational force to altitude. He made no connection at all between the supposedly higher velocity of the cannonball at point Z and either gravity or any possible notion of impetus. He made it quite clear at the outset that he knew that the small changes in altitude shown on the diagram would have had an insignificant effect on the gravitational force and thus showed no evidence that his ideas on gravitation were seriously at variance with Newton's.

EXAMPLE 2: INTERVIEWEE 2 ITEM 18

18. In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by

A. Block A
B. The earth
C. The string
D. The table
E. The pulley



SOURCE: # 1 from: Helm, H. (1978, 1980); also used in Ivowi, U.M.O. (1984)

Interviewee 2 selected two options, A and B, for his answer to this question, i.e. the hanging block, 'A' and the earth and justified his choice as follows:

".. *block A is pulling it down, so that would be the first answer, block A and then the earth is pulling block A down with regards to gravity .. so it's the earth indirectly with its effect on B.*"

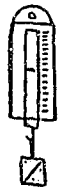
This is a perfectly reasonable answer if one interprets the question as asking for the origin of the force on block B. In addition, Interviewee 2 went on to indicate that he recognised the role of the string as that which is directly in contact with and therefore pulling block A, thus further suggesting that, rather than holding the target misconception, he had simply interpreted the question as I have indicated. This, coupled with the language confusion he then went on to demonstrate when he confused 'option D' with the table in the diagram, calling it "*block D*", led me to count this as a false positive of language origin.

OTHER EXAMPLES: Interviewees 2, 3, 4, 7 & 8, ITEM 8;
Interviewees 2 & 8 ITEM 12.

ii) FALSE POSITIVES NOT LINKED TO LANGUAGE PROBLEMS

EXAMPLE 1. Interviewee 2 ITEMS 16 & 17

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

A. 30 N
B. slightly more than 20 N
C. exactly 20 N
D. slightly less than 20 N
E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

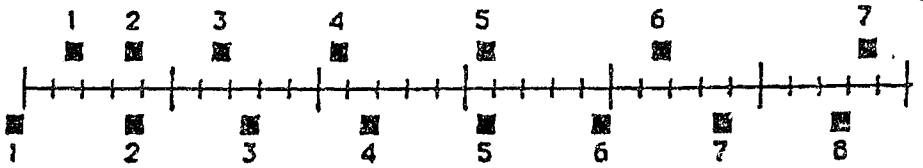
A. 30 N
B. greater than in Q 16 but less than 30 N
C. exactly 20 N
D. less than in Q 16 but greater than 10 N
E. 10 N

SOURCE: #'s 16 & 17 from: Moolla, M., (1989)

Interviewee 2's answers to these two items represent an interesting example of a false positive. In the first place, the only evidence of any language influence in the interviewee's explanations suggests that his interpretation of the question was actually more accurate then Moolla's. The questions both ask the interviewee for the `reading on the spring balance'. There is no spring balance made that can detect the insignificant changes in weight with the relatively small increases in altitude described in these two questions and thus the correct answer for both questions is Option C. Interviewee 2, when excluding the un-targeted misconceptions discussed below from his reasoning, chose Option C as his final answer for both questions during the interview. What is interesting here is that Moolla rated choice of Option C as evidence of the misconception that `force of gravity does not vary with altitude', suggesting that he perhaps misinterpreted the wording of his own question. Whatever the case, interviewee two's original choice of option B was not made because he held the target misconception or because of language interference but rather because of interference in his reasoning by the two un-targeted misconceptions (see 4.2.3 below) and his answers to these two questions must therefore rate as false positives.

EXAMPLE 2: Interviewee 9 ITEM 7

* The positions of two blocks at successive 0.02 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



7. Do the blocks ever have the same speed?

A. No.
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instant 2 and 5.
E. Yes at some time during interval 3 to 4.

SOURCE: # 20 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

In answering this item, Interviewee 9 made an initial choice of Option E (the key), then crossed out his choice and opted for a distractor, Option D, which according to the original authors is indicative of a misconception in which position and velocity are un-discriminated. (Hestenes et al, 1992) During the interview, this interviewee made it clear that he regarded option E as the correct answer:

"*Er I was thinking, that one, that one; um .. sometime between three and four .. three, four .. ja, I'd take E.*"

Prior to this statement he also indicated that he was using the graphic data correctly, in using the spaces between the blocks in the diagram as an indication of speed rather than their position. When explaining how he knew that the two moving objects were travelling at the same speed at a designated point in the diagram, he said:

"*Er because the spaces are .. look, I didn't take a measurer, but they're // because they're the same distance apart.*"

He finally indicated that he had no idea of his reasoning at the time of the written test when he first chose the right answer and then rejected it and opted for an incorrect answer:

"*Q: But .. can you .. possibly remember why you made that change originally?*

A: No, I was being stupid. I dunno, but .. when I look at it now it's incorrect ...."

This can thus be regarded as a false positive of unknown origin.

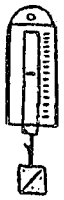
OTHER EXAMPLES: Interviewee 2 ITEMS 16 & 17

b) UN-TARGETED MISCONCEPTION

A interviewee was considered to hold an un-targeted misconception if his responses to the interview questions indicated that he did in fact hold a genuine misconception, but not the one targeted by the item according to the original researcher.

EXAMPLE 1. Interviewee 2 ITEMS 16 & 17

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

    A. 30 N
    B. slightly more than 20 N
    C. exactly 20 N
    D. slightly less than 20 N
    E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

    A. 30 N
    B. greater than in Q 16 but less than 30 N
    C. exactly 20 N
    D. less than in Q 16 but greater than 10 N
    E. 10 N

SOURCE: #'s 16 & 17 from: Moolla, M., (1989)

According to Moolla, a choice of option B for ITEM 16 is indicative of the misconception where the force of gravity is believed to increase with altitude. Rather than presenting evidence for this belief (see above), Interviewee 2 justified his answer with an explanation involving two un-targeted misconceptions regarding air pressure. Firstly he showed clear evidence that he believed that air pressure acts downwards:

" *.. so there's less air pressure pushing down the effect of the spring balance ..*"

And later:

"*I was thinking of air pressure pushing down on the object which would increase or decrease the weight of it.*"

Secondly he presented evidence at least suggestive of the belief that air pressure increases with altitude:

" *.. obviously if you go higher the air pressure will be more ..* ".

Although this statement is logically consistent with his notion that the spring balance reading would increase with altitude, it does not amount to conclusive evidence as it is in contradiction with two earlier (correct) statements that air pressure decreases with altitude.

For ITEM 17, interviewee 2 indicated that he had used the same reasoning, i.e. involving the downward action of air pressure interfering with the spring balance, in his choice of option:

"*Ja, I just took air pr- air pressure again.*"

EXAMPLE 2. Interviewee 5 ITEMS 16 & 17

Interviewee 5 answered ITEMS 16 and 17 using the same un-targeted misconception as that demonstrated by Interviewee 2, i.e. that air pressure acts downwards and thus assists gravity (see above). When asked to explain how air pressure would affect the reading on the spring balance, his reply was:

" *Well because um if you have um .. er air pressure, um higher air pressure then obviously there would be more of a downward force upon it but if you have er less air pressure there would be .. less - less of downward force on it so the measurements .. the measurements will be different.*"

It was also clear from a subsequent statement that he had used this reasoning in both of the items. It was equally clear that he did not hold the second of Interviewee 2's un-targeted misconceptions; he at least got the relationship between altitude and air pressure the right way round:

" *Er I would say slightly less than twenty newtons because as you go up the air pressure .. decreases*".

OTHER EXAMPLES: Interviewee 3, ITEM 10; Interviewee 5, ITEMS 13 & 20.

c) TRUE (or TARGET) MISCONCEPTION

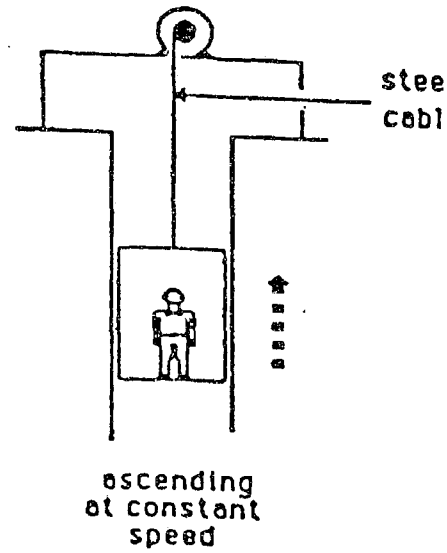
Here an interviewee, having answered an item in the written test in such a way as to suggest that he held the misconception targeted by the original researcher, then confirmed by his answers during the interview that he did indeed hold that misconception.

EXAMPLE 1: Interviewee 2, ITEM 9

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



SOURCE: # 18 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

The interviewee chose two options as his answer, A and D. Each of these answers, according to Hestenes et al, can be regarded as evidence that the interviewee holds a misconception, namely `largest force determines motion' and `only active agents exert forces' respectively. I would prefer to re-word the first of these as: `velocity (rather than acceleration) is a direct result of unbalanced forces'. The interviewee indicated twice during the interview that he believed that a non-zero velocity is only possible if forces are unbalanced:

"*.. I said that the upward force on the elevator was greater than the downward force of gravity because if it wasn't then the elevator wouldn't be moving up ..*"
And:

" *I said if the amount of upward force was equal to the downward force of gravity the thing wouldn't be moving, it would be stationary; ..*".

This, coupled with the interviewee's choice of Option A, was for me sufficient to warrant confirmation as a target misconception. Evidence confirming the second misconception, i.e. that targeted by Option D, was not forthcoming and no conclusion was drawn (see below under `Possible Misconception').
The interviewee also stated that he had difficulty understanding Option E, which I will discuss later under `Stated Language Difficulty', [paragraph #, page #].

EXAMPLE 2: Interviewee 4 ITEM 4

4. A stone falling from the roof of a single story building to the surface of the earth;

   A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
   B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
   C. speeds up because of the constant gravitational force acting on it.
   D. falls because of the intrinsic tendency of all objects to fall toward the earth.
   E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

SOURCE: No. 17 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992).
Interviewee 4's chosen answer to this item was Option A, which was rated as evidence of a misconception, i.e. that `force causes acceleration to terminal velocity' by Hestenes et al (1992). In explaining his choice, Interviewee 4 said that the stone would reach terminal velocity:

"*.. because once you drop it, it will go faster and faster and then it can't go any faster because of its weight, ... that's why.*"

When asked to enlarge on this, the interviewee said again:

"*I think it's got something to do with the weight ..*"

He said later that he couldn't remember what the actual value of terminal velocity was, "*but it depends on how heavy the object is* ..". When pressed even further and asked to describe the stone he had envisaged said:

"*Er I'd say a very small stone .. because it's very small so it's terminal velocity would be reached very quickly, 'cause it's very light; so it would be very small so there would be less friction on it, so it would speed up a lot more quickly than a big stone.*"

He thus demonstrated that even when bringing `air friction' into the picture, his understanding of its role was at best incomplete. `Target Misconception' seems therefore to be a reasonable conclusion in this case.

OTHER EXAMPLES: Interviewee 7 ITEM 1; Interviewee 5 ITEMS 1, 2 & 3

d) POSSIBLE MISCONCEPTION

A possible misconception was registered when the interviewee presented evidence suggestive of a misconception, but not sufficiently strong evidence to warrant confirmation.

EXAMPLE: Interviewee 2 ITEM 9

Interviewee 2's choice of Option D in Item 9 is suggestive of the misconception that `only active agents exert forces' (Hestenes et al, 1992). Unfortunately Interviewee 2's comments during the interview did not amount to more than just a suggestion that he did indeed hold this misconception:

" .. *I wasn't really sure what kind of force would be exerted on the elevator by the cable, there's only the upward force of movement and that's due to the fact that the cable's being shortened* ..".

Accordingly, I was not able to rate this one as anything more definite than a possible misconception.

OTHER EXAMPLE: Interviewee 6, ITEM 1.

e) FALSE NEGATIVE

For a false negative the interviewee would have to answer the written item correctly and then reveal in the interview that he did, in fact, hold the target misconception. In this study only one such instance occurred.

EXAMPLE: Interviewee 6, ITEM 2

2. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box

   A. If the force applied to the box is doubled, the speed of the box will increase to 8.0 m/s.
   B. The amount of force applied to move the box at a constant speed must be more than its weight.
   C. The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
   D. The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
   E. There is a force being applied to the box to make it move but the external forces such as friction are not 'real' forces they just resist motion.

SOURCE: #28 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

According to Hestenes et al (1992), Interviewee 6's choice of Option C puts him in the clear as it is the key for this item. His responses to interview questions reveal another story. On being asked to comment on the options he hadn't chosen, Interviewee 6 said of Option A:

"*I think A would .. might be correct as well, if you double the force, the speed should double as well ..*".

This cannot be passed off as a slip of the tongue in which he said (having read) 'speed' when he actually meant 'acceleration', as he subsequently made another four comments to the same effect, in the course of explaining why he agreed with the Option A statement. The misconception that 'velocity (or speed) is proportional to applied force' is specifically targeted by Option A of this item and Interviewee 6

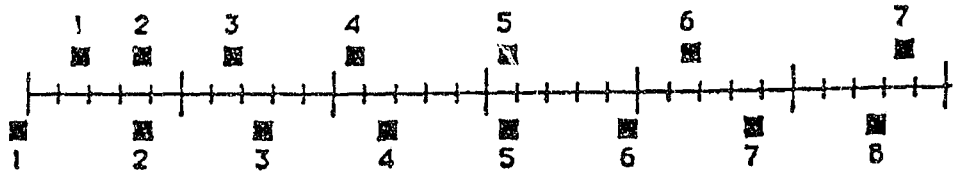
demonstrated in the interview that he held it. His original failure to choose Option A and his choice instead of Option C during the written test masked the fact that he held this misconception, and thus can be rated as a false negative. No other examples of false negatives emerged during the interviews, but could possibly have occurred in interviewees that were not selected to be interviewed, and would thus not have been detected.

f) NO MISCONCEPTION

Here the interviewee, having answered the written item correctly, then confirms during the interview that he holds no misconception.

EXAMPLE 1: Interviewee 6 ITEMS 7 & 8

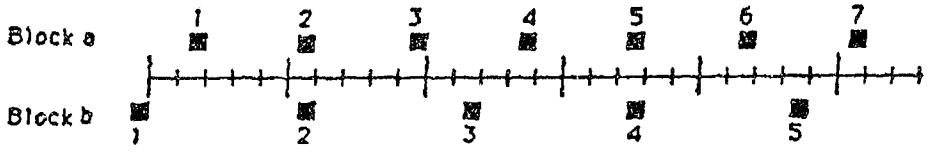
* The positions of two blocks at successive 0.02 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



7. Do the blocks ever have the same speed?

A. No.
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instant 2 and 5.
E. Yes at some time during interval 3 to 4.

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



8. The acceleration of the blocks are related as follows:

A. acceleration of `a' > acceleration of `b'.
B. acceleration of `a' = acceleration `b' > 0.
C. acceleration of `b' > acceleration `a'.
D. acceleration of `b' = acceleration `a' = 0.
E. not enough information to answer.

SOURCE: #'s 20 & 21 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

In both cases Interviewee 6 chose the keys as his answers. For item 7, he explained quite clearly that he based his reasoning on the relationship between the speed of the moving block and the spacing between successive images of the block in the diagram:

" *.. basically you can see that the speeds are the same if the the distances between .. er .. between the blocks at certain intervals are the same ..*".

He also indicated that he used the same reasoning in rejecting the distractors:

"*.. at instant five, .. er you can see that the top block, the distance between four, five and six has gotten too big, so it's - it's going faster by that time ..*".

In item 8 he is less explicit:

"*.. okay both of er block A and B have .. constant acceleration - so in other wor- zero acceleration - constant velocity, so .. the acceleration of A will be zero and the acceleration of B will be zero, so D was .. the best answer there.*"

However, as he arrived at the correct answer, it seems to be a safe assumption that

he once again used block spacing in the diagram as an indication of speed. As this is how a seasoned physicist would have reasoned in answering the same questions, there is no reason to think that Interviewee 6 held any misconception. It is worth noting at this point that this interviewee did make a momentary language slip, in which he said `acceleration' when he meant `velocity' (see quote above); the fact that he immediately corrected himself indicates that it was merely a slip and that he was capable of distinguishing between the two words and presumably between the two concepts.

OTHER EXAMPLES: Interviewee 5 ITEMS 7 & 8;
Interviewee 6 ITEM 13

g) LANGUAGE CONFUSION

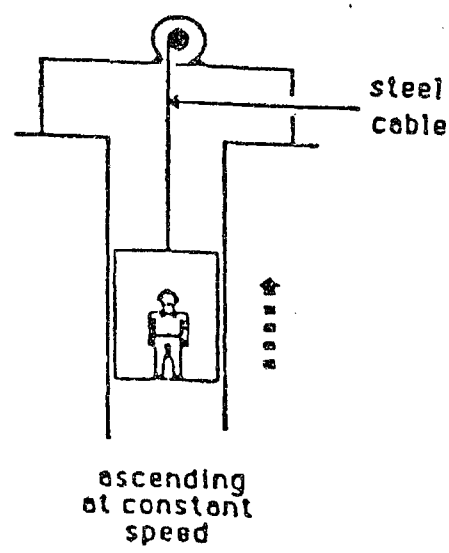
This category was exemplified by the interviewee showing clear evidence of misinterpreting the question text, or of weakness in his own language usage, but not that he was actually aware of his difficulty, i.e. there was no `up front' declaration of the difficulty by the interviewee. Interviewee 6's `slip of the tongue' in Item 8 (mentioned above) would not qualify because he immediately corrected himself; thus showing that not only was he aware of the mistake, but that it was not an inherent language weakness.

EXAMPLE 1: Interviewee 5 ITEM 9

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



SOURCE: # 18 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

Having chosen option D as his answer, Interviewee 5 was asked to explain his reasoning, to which he replied that while the `force of the cable' would not be able to lift the elevator, the `shortening' of the cable would. When he was then asked to explain his meaning for `force of the cable' he replied:

" .. *the strength of the cable, basically with which .. the force of the cable relative to the .. the elevator, // the elevator's a certain weight and the cable will be able to resist that weight, it won't break.*"

This indicates that to him `force of the cable' meant something akin to `breaking strain'. It is not clear whether this was simply conceptual mis-labelling or if there was conceptual merging as well; the matter would have required further investigation beyond the scope of the interview at the time. However there can be little doubt that there was a language problem in operation and that it affected the interviewee's reasoning. Also, unlike Interviewee 6's immediate awareness of his slip of the tongue mentioned above, Interviewee 5 gave no indication of any awareness of his difficulty.

EXAMPLE 2: Interviewee 8 ITEMS 4 & 8

4. A stone falling from the roof of a single story building to the surface of the earth;

   A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
   B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
   C. speeds up because of the constant gravitational force acting on it.
   D. falls because of the intrinsic tendency of all objects to fall toward the earth.
   E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

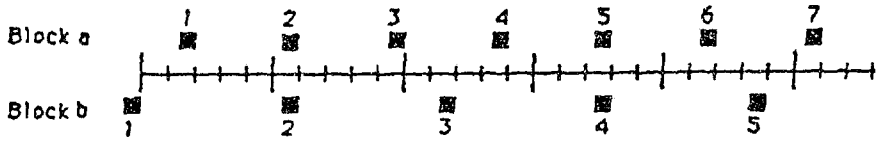
SOURCE: No. 17 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992).

In the course of probing for the reasoning behind Interviewee 8's choice of option A in this item, I asked him for his estimate of the height of the building. To this he replied: "*I'd say about .. about a hundred metres.*"

It is difficult to account for this answer other than to suppose that the interviewee somehow missed the statement in the question stem that the stone was falling from a single storey building. As a small enough 'stone' could conceivably reach terminal velocity within a one hundred metre fall, there is little doubt that this reading or interpretational error played a part in the interviewee's choice of option.

ITEM # 8

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



8. The acceleration of the blocks are related as follows:

A. acceleration of `a' > acceleration of `b'.
B. acceleration of `a' = acceleration `b' > 0.
C. acceleration of `b' > acceleration `a'.
D. acceleration of `b' = acceleration `a' = 0.
E. not enough information to answer.

SOURCE: # 21 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

Interviewee 8 showed confusing use of language on several occasions while being questioned on this item. The best example of this is where, having stated under questioning that from the evidence in the diagram, the two blocks have the same acceleration, he then immediately picked on option A, which states that the acceleration of block A was bigger than that of block B, as his final answer for the item, not noticing the inherent contradiction.

OTHER EXAMPLES: Interviewee 2 ITEM 4, 7 & 19

h) STATED LANGUAGE DIFFICULTY

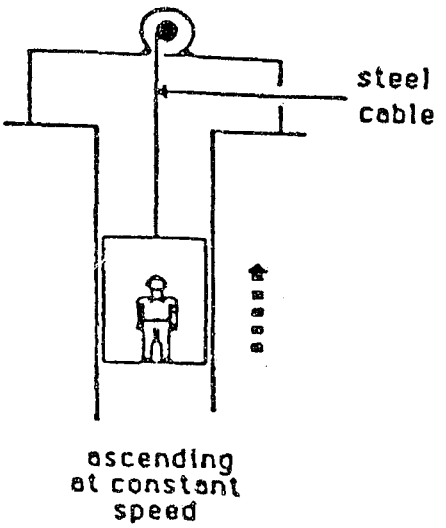
Here an interviewee actually stated during the interview that he had had difficulty interpreting the question text. This difficulty may or may not have obviously interfered with the interviewee's reasoning

EXAMPLE 1: Interviewee 2, ITEM 9

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



SOURCE: # 18 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

When asked to explain why he had not chosen Option E for this item, Interviewee 2 said:

"*.. E, I didn't really know what it was talking about, `the upward force is greater than the downward force .. combined effects of air pressure and gravity', I wasn't really sure what that was talking about, so that's why I didn't put that option 'cause I didn't really understand it.*"

Here he not only stated that he was having difficulty understanding the words, but that that was why he rejected the option; i.e. his difficulty to understand the text affected his answering of the question.

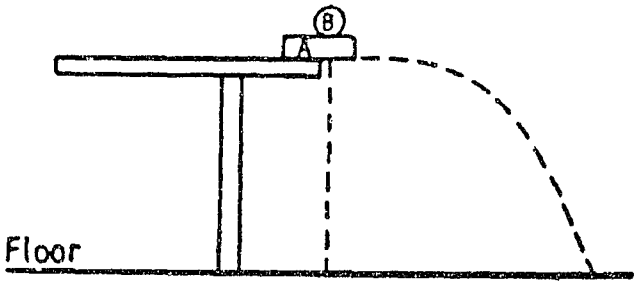
OTHER EXAMPLES: Interviewee 1 ITEM 19; Interviewee 3 ITEM 11; Interviewee 5 ITEM 16

i) NO CONCLUSION

If the interviewee presented no clear evidence of any specific outcome during the interview no conclusion was drawn.

EXAMPLE 1: Interviewee 2 ITEM 1

1. The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

SOURCE: # 4 from: Ivowi, U.M.O. (1984)

Interviewee 2's original choice was Option A, which he then cancelled and chose Option E. Option E was the key for this item according to Ivowi and thus Interviewee 2 could be judged as not holding the target misconception.

Unfortunately Interviewee 2 gave no clear explanation during the interview of either why he liked Option E, or why he initially chose Option A and then reconsidered. His statements provide at best a tantalising suggestion that he may have been confusing the horizontal and vertical components of object A's motion:

"Well, A originally going a bit faster than B, to get to the equal line, so A would originally have a higher initial velocity than B but their final velocity would be the same .. at least that's what I figured."

This would have been consistent with his initial choice of Option A, but does not explain his final choice of Option E or why he rejected Option A. I felt thus that it would be safest to designate this as a `no conclusion'.

OTHER EXAMPLES: Interviewee 2, ITEMS 4 & 5; Interviewee 5 ITEMS 5 & 9; Interviewee 9 ITEM 11

j) LANGUAGE ORIGIN

This was not a data category per se but rather a qualifier for other data categories such as the false positive. A choice of option was deemed to have a `language origin' when the interviewee showed clear evidence during the interview that the choice was made because of an interpretation of the question text not intended by the original researcher. This need not imply poor wording of the question or weak language skills in the interviewee. A interviewee with good language skills may see a variety of ways of interpreting a given piece of text, even when there is nothing `wrong' with the text. Examples have been dealt with under the relevant data categories above.

k) UNKNOWN ORIGIN

This was also a qualifier rather than a data category in its own right and occurred when the interviewee was unable to account for his choice of option; i.e. was mystified by his own answer. Examples have been dealt with under the relevant data categories above.

The results have thus far been presented as an overview, each data category being dealt with in turn. Another perspective and different insights can be gained from the data captured from an individual interviewee. For this purpose, the data of each of four selected interviewees will now be presented.

5.4.2 DISCUSSION OF SELECTED INDIVIDUAL INTERVIEWEES

The Interviewees selected here for discussion are those in whose interviews the more 'interesting' data categories were well represented; particularly the false positives, (both those linked to language interference and those that were not) and un-targeted misconceptions.

a) Interviewee 8

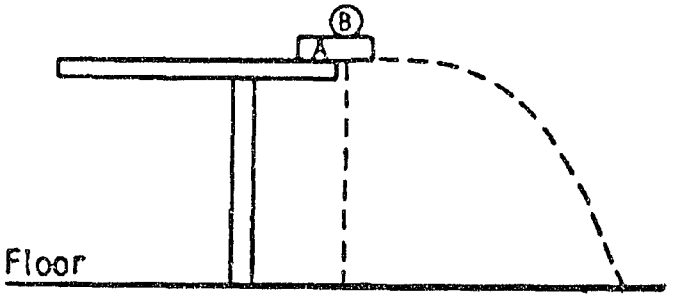
Interviewee 8 was selected to be interviewed because he changed two of his initial choices, in one case rejecting a distractor and then opting for the correct answer; in the other rejecting a correct answer and then opting for a distractor. He also chose answers which some of the source authors would have interpreted as indicative of misconceptions but were not in fact wrong - for example Option C of items 1, 1\ & 17. This interviewee exhibited six false positives of language origin, the highest number in the group. (One other Interviewee, No. 9 exhibited a larger number of false positives, eleven in all, but only one of these could definitely be linked to language.) Also evident in Interviewee 8's transcript is one un-targeted misconception and four instances of language confusion. In only two instances, and in neither case without doubt, did items identify target misconceptions. In three other instances Interviewee 8's correct answers were confirmed as being based on good reasoning. Also only revealed in the interview was that the Interviewee's original selection of Options for items 3 and 4 involved a simple error of orientation: the Interviewee placed his crosses one line too low for both items, then noticed his

error and made the necessary adjustment. Thus his 'reconsideration' of his choices in these two items is of no significance in the context of this study.

i) The false positives

In ITEM 1, Interviewee 8 chose Option C, which the source author (Ivowi, 1984) would have rated as incorrect, and as evidence that the Interviewee had reasoned without taking the objects' initial states of motion into account .

1. The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

SOURCE: #28 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

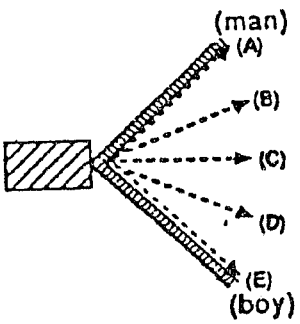
Probing in the interview revealed evidence that the interviewee had taken the initial velocities into account - when asked why he preferred Option C to Option E, Interviewee 8 was not able to articulate a clear answer but did indicate that he regarded them as similar:

"They both have the same reasoning, C and E, both initial velocity - the initial velocity of A and B were both zero, 'cause they were both stationary and then the force was applied to A."

In this statement the Interviewee made it quite clear that he was taking the initial state of motion of both objects into account and thus did not hold the `misconception' specified by the source author (Ivowi, 1984) for this item. While the Option C text makes no mention of initial states of motion at all, the stem states that object B was `resting' on object A. The assumption that object A was also at rest would not even have involved any significant `creative reading' on the part of the interviewee.

In ITEM 6, the Interviewee came close to stating outright that he found the text confusing.

6. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as shown on the diagram to the right. Which of the indicated paths (A - E) would most likely correspond to the path of the crate as they pull it along?



SOURCE: # 19 from: Hestenes, Wells & Swackhammer (1992)

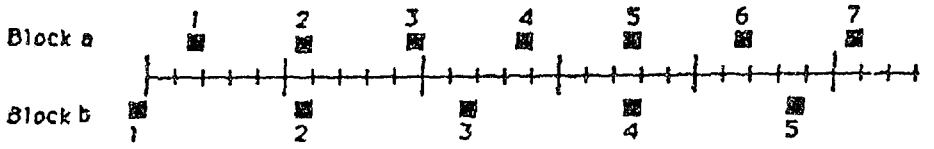
He articulated clearly that his interpretation did not include the assumption that the man must necessarily be exerting a larger force than the boy:

".. they don't - they don't give you an indication of - if they're pulling at the same - with the same force, or is the man is stronger than the boy or the boy is stronger than the man, so I said C, it'll go straight forward."

The Interviewee's compromise assumption that the two people were pulling with forces of equal magnitude led naturally to the choice of Option C, as the vector sum of two such forces acting as shown would be a resultant in the direction indicated by Option C.

In ITEM 8, as discussed earlier under paragraph 5.4.1 n on page 75, the Interviewee rejected his answer to the written test during the interview.

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



8. The acceleration of the blocks are related as follows:

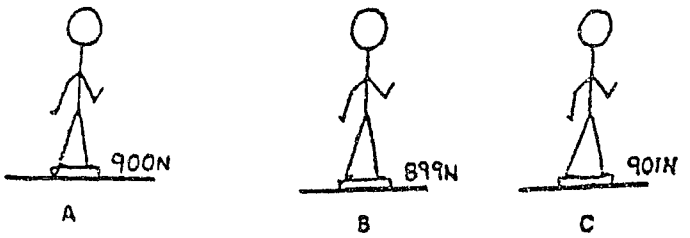
   A. acceleration of 'a' > acceleration of 'b'.
   B. acceleration of 'a' = acceleration 'b' > 0.
   C. acceleration of 'b' > acceleration 'a'.
   D. acceleration of 'b' = acceleration 'a' = 0.
   E. not enough information to answer.

SOURCE: # 21 from: Hestenes, Wells & Swackhammer (1992)

Having initially related gap size to acceleration, he spotted his mistake during the interview and rejected his original choice of Option C. He then related gap size to velocity and reached the correct conclusion. Here the interference in the interviewee's reasoning by language could not be demonstrated beyond doubt although there is a possibility that he was interchanging the words 'velocity' and 'acceleration'. I found no reason to suspect that he was confusing the two concepts. The language confusion rating was due to the Interviewee's failure to see the contradiction between stating that the accelerations of the two objects were equal and an approval of Option A, which states that they are not.

ITEM 14 presents a change in the pattern in that there was no certainty that a false positive was being presented.

Three men of equal masses are each standing on stationary scales at different places on earth. The numbers represent their weight as shown by the scale.



14. Who experiences the greatest gravitational force?

A. A.
B. B.
C. C.
D. They all feel an equal gravitational force.
E. We cannot say because we need more data.

SOURCE: #'s 14 & 15 from: Moolla (1989)

The interviewee's answer to this item seems to have been inspired by what he had been taught. He stated that:

" .. - *at all points on the surface of the earth, the - you'd have the same effect of gravity on you.*"

When asked to clarify what he meant by 'effect of gravity', he said:

" .. *effect of gravity as in the downward force or your weight* ..".

This could mean that the Interviewee was indeed confusing force of gravity with gravitational acceleration as the source author (Moolla, 1989) would have concluded - secondary science students are taught that gravitational acceleration is the same everywhere for a body falling freely near to the surface of the earth. However, the Interviewee may not necessarily have been doing anything of the sort - to conclude from this teaching that if the acceleration due to gravity of a given

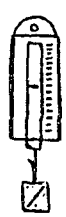
falling object was the same everywhere on or near to the surface of the earth, then the force of gravity must also be the same everywhere, would simply be consistent with Newton's second law and therefore would not in itself be evidence of a misconception. Further probing revealed that the interviewee did link an increase in altitude with a decrease in weight, and also that he had a fair degree of insight into the quantities involved. On being questioned on how great a change in altitude would be needed to make a more than negligible difference to weight, he said:

"I would say out of the atmosphere, not - or maybe not so - quite so drastic but .. pretty much out of the atmosphere to feel a less - or less of a force of gravity from the earth."

While this indicates that he did not hold the main misconception supposedly probed by the item, there is still some doubt about whether or not he held the one specifically indicated by choice of Option D and he apparently did completely miss (or ignore?) the import of the figures given in the diagram for the readings on the scales.

In ITEMS 16 and 17, Interviewee 8's choice of Option C in both cases would have led the source author to conclude that he "*was working in the framework in which weight, or the force of gravity, does not depend on the distance from the earth's centre.*" (Moolla, 1989, p 21)

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

A. 30 N
B. slightly more than 20 N
C. exactly 20 N
D. slightly less than 20 N
E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

A. 30 N
B. greater than in Q 16 but less than 30 N
C. exactly 20 N
D. less than in Q 16 but greater than 10 N
E. 10 N

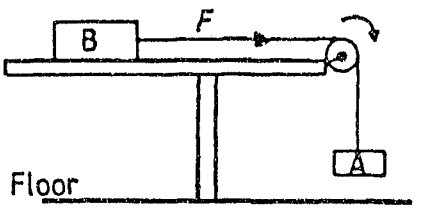
SOURCE: #'s 16 & 17 from: Moolla, M., (1989)

On being asked to justify his choices, Interviewee 8 said that the changes in altitude "*would have had very .. minimal effect on the object's er weight*" and that he thought Option C in both items, while not reflecting exactly the weight of the object in the two positions, would be the best approximation of the reading. As he seems to have been interpreting the questions literally, i.e. as asking for the reading on the balance, he was demonstrating a false positive of language origin.

ITEM 18 supposedly tests for failure to recognise that the agent in contact must exert a contact force. (Ivowi, 1984)

18. In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by

A. Block A
B. The earth
C. The string
D. The table
E. The pulley



SOURCE: # 1 from: Helm (1978), Helm (1980) Also used in: Ivowi (1984)

Interviewee 8 justified his choice of Option B thus:

" .. *the force of the earth in indirectly - indirectly affects the .. the block B which is sitting on the table, because it er first affects A, and pulls A towards the .. towards the earth and as A falls towards the earth so B would move um ..*"

and then:

"*.. - well the string is directly actually um affecting the er - affecting B, is pulling B at the same force that er .. A is pulling on the string, that the earth is pulling on A ..*"

One of the source authors (Ivowi, 1984, p 280) remarks:

" .. *the weight of block A in* [the question] *produces the tension in the string, it is a remote causal agent of the force F.*"

and goes on to say that:

"*the contact force F, acting on B must be exerted by the agent in contact with B.*" (Ivowi, 1984, p 280)

Interviewee 8's explanation, allowing for some difference in emphasis and also for his poor articulation, is remarkably similar to that of the source author, yet his choice of Option B would have been judged as evidence of a misconception. His interpretation of the question was that it was asking for the orgin of the force F, which is a reasonable interpretation and qualifies Interviewee 8's response to this item as a false positive of language origin.

ii) Language confusion

The analysis of Interviewee 8's transcript revealed four instances of language confusion. Two of them have already been discussed under 'language confusion' (paragraph 5.4.1: h, p 79) in the discussion of individual data categories. Subsequent comments on these two items can thus be regarded as supplementary to the earlier ones.

ITEM 4 (discussed earlier, see above) was one of the two instances where the interviewee altered his choice, although probing revealed that there was no significance in this as it was a simple error of orientation. It was also one of the two instances where a target misconception could not quite be confirmed.

4. A stone falling from the roof of a single story building to the surface of the earth;

   A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
   B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
   C. speeds up because of the constant gravitational force acting on it.
   D. falls because of the intrinsic tendency of all objects to fall toward the earth.
   E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

SOURCE: No. 17 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992).

In this item, the source authors rate choice of Option A as indicative of the `alternative' notion that a "*force causes acceleration to terminal velocity.*" (Hestenes, Wells and Swackhammer, 1992, p 144) At no time during the interview did Interviewee 8 mention the role played by air `friction' on a falling object but what stopped me rating this as a target misconception was the interviewee's bizarre notion of the height of the building, which according to his interpretation was " .. *about a hundred metres*" high. As it is not inconceivable for a sufficiently small, light object to reach terminal velocity within a one hundred metre fall, there is a possibility that this interviewee did include air resistance in his mental model but did not for some reason mention it at the time of the interview. The language confusion rating was due to his rather original idea of the height of a `one storey' building.

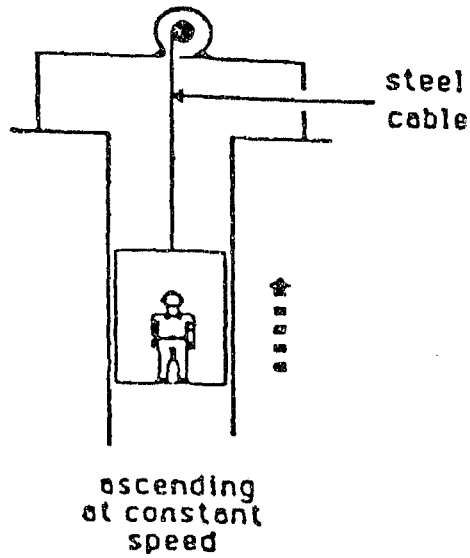
In ITEM 9, Interviewee 8 chose Option A, allegedly indicative of the misconception that the "*largest force determines motion*", Hestenes, Wells and Swackhammer,

1992, p 144) or more specifically that there has to be an imbalance in the forces acting to enable any motion to take place at all.

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



SOURCE: #18 from: Hestenes, D, Wells, M. and Swackhammer, G. (1992)

While Interviewee 8 might possibly have held the target misconception but nothing in the interview discourse confirmed it, leading me to rate this as a `no conclusion'. The `language confusion' rating was because the interviewee's statements were notably inarticulate and he seemed entirely to miss the stem statement that air resistance was to be ignored. Of Option E he said simply: "*I just didn't agree with that*" and went on to explain, in response to a request to enlarge on the notion of air

pressure, that it was caused by particles colliding with the elevator and causing it to slow down, which is a fair description of `air resistance'. Not once did he point out that the question stem had ruled the phenomenon negligible.

In ITEM 20, Interviewee 8's choice of Option E would have been judged by the source author as indicative of a misconception termed "*inability to identify forces*" (Jordan, 1995, p 39).

20. Which one of the following assertions concerning an astronaut standing on the moon, is true?

    A. The astronaut experiences no force, because there is not an atmosphere.
    B. The astronaut experiences no force, because only bodies near the earth are attracted by gravitation.
    C. The astronaut only experiences a downward force as a result of the moon,s gravitational attraction.
    D. The astronaut experiences a downward gravitational force and an upward force exerted by the moon's surface.
    E. The astronaut only experiences an upward force exerted by the moon,s surface.

SOURCE: #5 from: Jordan (1995)

In the course of explaining his reasoning, the interviewee read out parts of the question text. When reading Option E, he omitted the word `only', which changes the meaning of the text to the extent that no misconception is necessary for agreement with the option. There was however, definitely a language problem involved here: the omission of `only' is an example of `creative reading' or `unconscious editing'.

He made a case for Option B on the basis of it referring specifically to the earth's gravitational attraction, an interpretation that might have surprised the source author somewhat and again, suggestive of some language confusion.

He also demonstrated a shaky understanding of the relationship between gravitational force and weight. After stating that the moon's gravitational force on the astronaut must be negligibly small, he then said: "*he has weights or something*

to keep him on the moon's surface ..", apparently not realizing that 'weights' wouldn't hold him down without a more-than-negligible gravitational force acting. This I rated as an un-targeted misconception.

Interviewee 8 single-handedly provided what was arguably the best body of data for the purposes of this study, i.e. his six false positives of language origin, together with his un-targeted misconception and four instances of language confusion comprise the best 'ammunition' in support of the contention that in multiple choice questionnaires, distractors are not chosen only by subjects who hold misconceptions.
The other three selected interviewees, while not serving this purpose quite so well, are also of great interest.

b) Interviewee 9

Interviewee 9 demonstrated the largest number of false positives, eleven in all, but only one of these was attributable to language interference. Two of the false positives were not confirmed.

ITEM 3 probes the interviewee's knowledge of the role of friction and the choice of Option A supposedly indicates a belief that an active force is needed to maintain motion. (Hestenes et al. 1992)

3. If the force being applied to the box in the preceding problem (A large box is being pushed across the floor at a constant speed of 4.0 m/s.) is suddenly discontinued, the box will;

   A. stop suddenly.
   B. continue at a constant speed for a very short period of time and then slow to a stop.
   C. immediately start slowing to a stop.
   D. continue at a constant velocity.
   E. increase speed for a very short period of time, then start slowing to a stop.

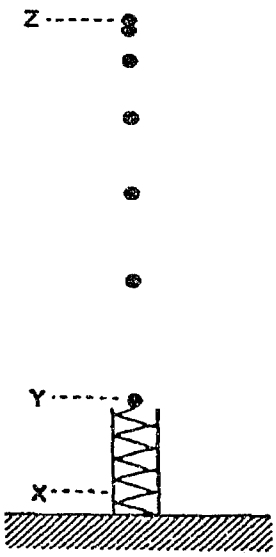
SOURCE: #29 from: Hestenes, Wells and Swackhammer (1992).

Having chosen Option A when he wrote the test, Interviewee 9 repudiated this choice in the interview, stating that he had been "*a bit naive*". After some thought, he settled on Option C, the correct answer for this item, as his final choice. His answers to questions during the interview indicated that his reasoning, while careless, was a reasonable approximation of Newtonian reasoning. The frictional force that he had envisaged as acting - to him the box was sliding on a "*very rough carpet*" - would have been high enough to make Option A almost reasonable provided 'suddenly' does not mean 'instantaneously'. This and his choice of Option C on reconsideration was only enough for me to rate this as a possible false positive as there was insufficient evidence to be completely sure.

A choice of Option C for ITEM 5 would have been interpreted as evidence of lack of discrimination between velocity and acceleration. (Hestenes et al, 1992)

* Refer to the diagram in the right margin to answer the following question.

The figure represents a multiflash photograph of a small steel ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, reaches its highest point at the point marked Z.



5. Assuming that the air resistance was negligible;

A. The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring)

B. The acceleration of the ball was decreasing on its way from point Y to point Z.

C. The acceleration of the ball was zero at point Z.

D. All of the above responses are correct.

E. The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

SOURCE: #26 from: Hestenes & Wells, (1992)

During the interview, Interviewee 9 changed his mind about his choice of Option C and stated a preference for Option D, which is suggestive of the target misconception. Indeed, on being asked to describe the motion of the ball, the interviewee started off using `acceleration' where he should have used `velocity' but then corrected himself and switched the words around:

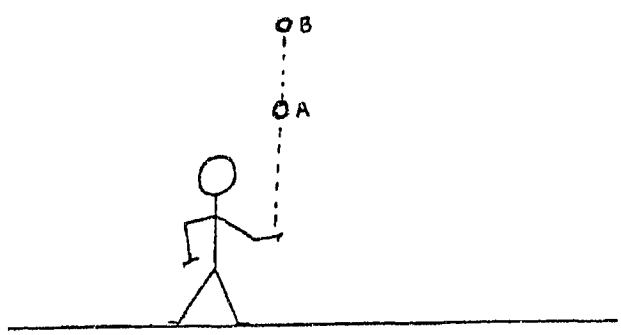
".. *Well just before point Y, it's - it's like .. full acceleration .. and it goes up, up, up, si-um acceleration decreasing - ja velocity decreasing, till it reaches point Z where it comes to a stop for a split second and comes all the way back down again; speeding - er er speeding up as it goes down .. till it reaches its lowest point, X, again.*"

When he used `velocity' in its correct place instead of `acceleration', there was little wrong with the interviewee's description. There was thus a temptation to rate this as a false positive. However the interviewee then cast doubt onto this conclusion be repeating his choice of Option D as his final answer.

Interviewee 9's reasoning when answering ITEM 7 and his subsequent interview comments are discussed in some detail under `false positives not linked to language problems' in the discussion of data categories, paragraph number 5.2.3 a) ii), pages 66 & 67.

In ITEM 10 Interviewee 9's initial choice and subsequent rejection of Option A was not significant as it was an orientation error - he thought he was answering ITEM 9, realised his mistake and corrected it.
According to the source author, a interviewee choosing Option E believes that gravity does not affect an upward-moving object. (Moolla, 1989)

An object is thrown straight up into the air. It leaves the thrower's hand, goes up to B and then comes back down to the thrower's hand. [Assume that there is no friction involved]



10. While the object is moving upwards, the direction of the force on it is

A. upwards.
B. downwards.
C. to the left.
D. to the right.
E. There is no force acting on it.

SOURCE: #1 from: Moolla (1989)

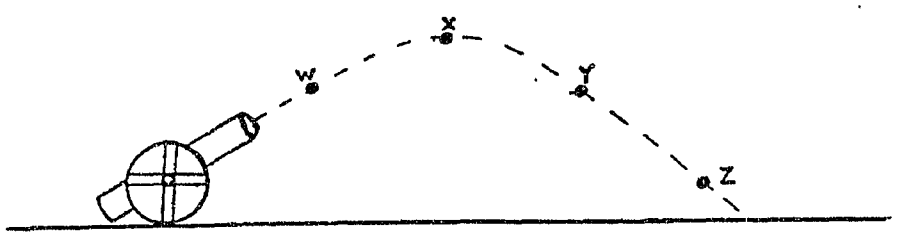
Interviewee 9's interview discourse was far from confirming the target misconception:

" .. *and then the act of gravity slowly brings it down and down and down, slower - slower, eventually it reaches its pinnacle, .. comes back down again.*"

Here, although expressing himself rather poorly, he was quite clearly saying that the force of gravity slowed the object down while it was on its way up. It seems that to him, the force referred to in the question text was not the force of gravity, but was the force applied to the object by the hand during the act of throwing. Unfortunately this could not be confirmed and this false positive could therefore not with certainty be attributed to language.

The belief that the force of gravity increases with altitude, which according to Moolla (1989) is the target misconception for ITEM 13, for which Interviewee 9 chose Option B, was not apparent in the interview dialogue.

A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball.
[Assume that there is no friction involved.]



13. A which of the points mentioned in the diagram is the effect of gravity the greatest?

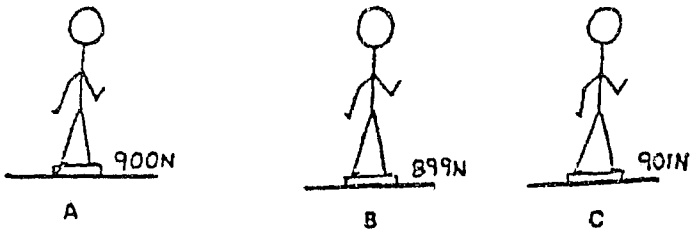
A. W
B. X
C. Y
D. Z
E. The effect of gravity is the same at all four points.

SOURCE: # 8 from: Moolla, M. (1989)

Rather than confirming that he held the target misconception, Interviewee 9 indicated that he would have chosen Z as the point where gravity was the strongest and could have been hinting vaguely that he had found the wording confusing.
He also presented evidence of an un-targeted misconception, i.e. impetus. His reasoning was that the `effect of gravity' would be the `greatest' (i.e. `most dramatic'?) at the top of the trajectory because there, gravity finally overcomes the impetus and turns the projectile back toward the earth.
The final conclusion was that this was a false positive coupled with an un-targeted misconception.

On re-reading ITEM 14 during his interview, Interviewee 9 realised without prompting that he'd mistakenly chosen Option B instead of Option C. His justification of his new choice indicated that his reasoning was not at odds with Newton's view of gravitation:
".. *the closer you get to the earth, the stronger the- the pull* .."

Three men of equal masses are each standing on stationary scales at different places on earth. The numbers represent their weight as shown by the scale.



14. Who experiences the greatest gravitational force?

A. A.
B. B.
C. C.
D. They all feel an equal gravitational force.
E. We cannot say because we need more data.

15. Who is closer to the earths centre?

A. A.
B. B.
C. C.
D. They are all the same distance from the earth's centre.
E. We cannot say because we need more data.

SOURCE: #'s 8 & 9 from: Moolla, M. (1989)

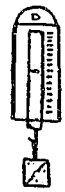
No reason for his original, incorrect choice was forthcoming, so this was rated as a false positive of unknown origin. The same applies to ITEM 15, where he also corrected his original choice and opted for C.

For ITEM 16, the interviewee again chose an option (C) which seemed to indicate that he believed that the force of gravity increases with altitude. Again he repudiated this choice in the interview, saying that he'd reasoned all the related questions the 'wrong way round'. When asked why, he said:

"*I dunno, maybe I just got mixed up, but .. it was a long day and // // not sure - obviously a bit delirious.*"

His new choice was Option D, which the source author (Moolla, 1989) regarded as the correct answer and subsequent probing revealed that to the interviewee, 'slightly less' meant a negligibly small difference. Thus his original response must rate as a false positive of unknown origin.

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

    A. 30 N
    B. slightly more than 20 N
    C. exactly 20 N
    D. slightly less than 20 N
    E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

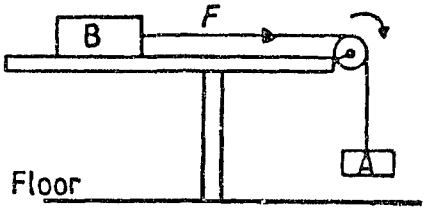
    A 30 N
    B. greater than in Q 16 but less than 30 N
    C. exactly 20 N
    D. less than in Q 16 but greater than 10 N
    E. 10 N

SOURCE: #'s 16 & 17 from: Moolla, M. (1989)

In ITEM 17, the same happened again but Interviewee 9 also revealed an interesting bit of 'creative reading'. He took the statement for Option D, which reads: "*less than in Q 16 but greater than 10 N.*" (Moolla, 1989 p 20) and read it as "*less than 16 N but greater than 10 N.*" Thus language confusion can be added to the false positive rating but because there was no obvious link between the two, the false positive was rated as of unknown origin.

In ITEM 18, the source authors (Helm 1978, 1980 & Ivowi 1984) did not specify what misconception the interviewee's choice of Option E supposedly signified; thus it is debatable whether this could qualify as a false positive.

18. In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by



A. Block A
B. The earth
C. The string
D. The table
E. The pulley

SOURCE: #1 from: Helm, H. (1978) Helm, H (1980) also used in Ivowi, U. M. O. (1984)

The interviewee did however show that he had interpreted the question as asking for the origin of the force and that there was thus a language problem, i.e. alternative interpretation.

The interviewee's choice was thus definitely influenced by language but was not definitely a false positive.

For ITEM 20, Interviewee 9 initially chose Option C, but reconsidered in the interview and opted for D, which is the correct answer.

20. Which one of the following assertions concerning an astronaut standing on the moon, is true?

A. The astronaut experiences no force, because there is not an atmosphere.
B. The astronaut experiences no force, because only bodies near the earth are attracted by gravitation.
C. The astronaut only experiences a downward force as a result of the moon,s gravitational attraction.
D. The astronaut experiences a downward gravitational force and an upward force exerted by the moon's surface.
E. The astronaut only experiences an upward force exerted by the moon,s surface.

SOURCE: #5 from: Jordaan, F. (1995)

Why he chose Option C when writing the test is unknown - the interviewee was unable to explain his choice: ".. *I dunno .. I just took a .. can't remember.*" Whatever the reason, in the interview he indicated a preference for Option D which is the correct answer, suggesting that he holds no misconception. Hence I rated this answer a false positive of unknown origin.

While Interviewee 9's data does not provide much evidence of any connection between language and false positives, the sheer number of false positives is a clear indication of the validity problem inherent in the twenty items in the questionnaire.

c) Interviewee 7

Interviewee 7 presented five definite false positives, three of them attributable to language.

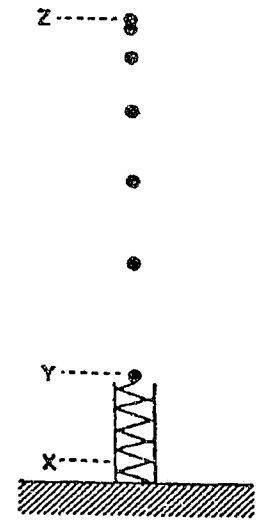
For ITEM 5, Interviewee 7 initially chose Option D, reconsidered and changed his choice to Option C.

Either of these choices could be interpreted as evidence of lack of discrimination between acceleration and velocity, but whether this was at a conceptual level or a purely verbal level is not so clear. During the interview, the interviewee showed a liking for Option E and some semblance of Newtonian reasoning:
"*I'd say the actual object slows down as it goes higher .. until it reaches Z and then it would accelerate back down, as it falls.*"

It is possible that the interviewee was merely interchanging the two words rather than confusing the two concepts and had simply not considered Option E at the time of writing the test.

* Refer to the diagram in the right margin to answer the following question:

The figure represents a multiflash photograph of a small steel ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, reaches its highest point at the point marked Z.



5. Assuming that the air resistance was negligible;

A. The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring)

B. The acceleration of the ball was decreasing on its way from point Y to point Z.

C. The acceleration of the ball was zero at point Z.

D. All of the above responses are correct.

E. The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

SOURCE: # 26 from: Hestenes & Wells (1992)

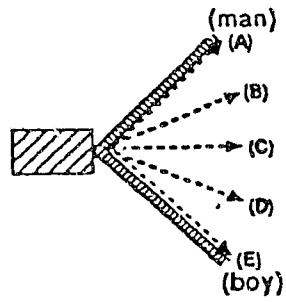
A firm conclusion for this item was not possible however, because he didn't abandon his liking for Options C and D. Thus a possible false positive of language origin was registered for this item.

In ITEM 6, the interviewee interpreted the situation described in the question text as the source authors did, i.e. the man exerting a larger force than the boy, but paradoxically chose Option D as his answer. In explaining his reasoning the interviewee used the word `angle' as a synonym not only for `direction' but also for `turning':

"*.. so I said they'd be pulling at angle D, because er the man is pulling stronger .. we think, so he would be .. going faster, I'd say pulling it faster, he's got more strength than the little boy, he would tend to angle round, 'cause he's pulling faster than the small boy, so he'd pull round and .. he would go faster,* [the boy] *would go slower*

and they'd tend to pull round towards D."

6. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as shown on the diagram to the right. Which of the indicated paths (A - E) would most likely correspond to the path of the crate as they pull it along?

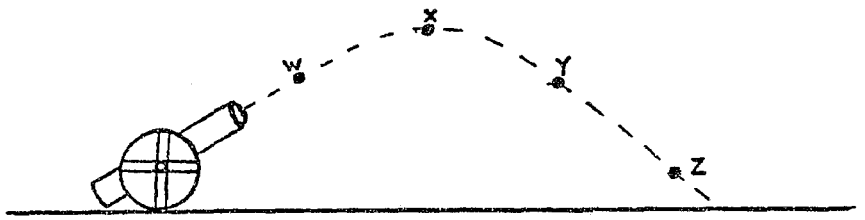


SOURCE: #19 from: Hestenes, Wells and Swackhammer (1992)

With the interviewee's novel uses of the word `angle' one wonders what other sorts of creative interpretations he might have indulged in. While the pivoting action he described may not be a reasonable prediction of the crate's behaviour, it does at least address the question which, as mentioned above, asks for the crate's likely path and not for the direction of the resultant force acting on it. As explained in Chapter 4, it is possible for the directions of an object's acceleration and of its motion to be in different directions and although this is not the case here, the interviewee's incorrect prediction of the crate's path does not constitute proof that he was unable to determine the direction of a resultant force by the superposition principle. The item thus failed to demonstrate that the interviewee held the target misconception and the response thus represents a false positive of language origin.

IN ITEM 12, choice of Option D supposedly indicates that a interviewee holds the misconception that the final velocity of an object (rather than its acceleration) is proportional to the applied force. (Moolla, 1989)

A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball.
[Assume that there is no friction involved.]



12. At which of the points mentioned in the diagram is the force on the cannon-ball the greatest?

A. W
B. X
C. Y
D. Z
E. The force is the same at all four points.

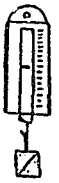
SOURCE: #8 from: Moolla, M. (1989)

Interviewee 7 indicated twice that he could see two possible interpretations of the question text: one, that the force referred to is the force of gravity and the other, that it is the force applied to the cannonball during the firing of the cannon. When asked which of the two he had opted for he answered that he had chosen the gravitational force. As point Z in the diagram is the point closest to the earth, it is the point where the force of gravity would be strongest, although admittedly by a negligible degree. His choice of Option D is therefore inconsistent with Newtonian reasoning only in terms of quantity and does not amount to proof that held the target misconception. His need to choose between the two possible interpretations of the question is an instance of language interference.

When considering the merits of the alternative interpretation he spoke of the force exerted on the cannonball by the cannon as being strongest at point W, which is suggestive of an impetus notion. This could rate as an un-targeted misconception as it was not indicated by Option D, even though it was one of the target misconceptions listed for the item.

ITEMS 16 & 17

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

    A. 30 N
    B. slightly more than 20 N
    C. exactly 20 N
    D. slightly less than 20 N
    E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

    A. 30 N
    B. greater than in Q 16 but less than 30 N
    C. exactly 20 N
    D. less than in Q 16 but greater than 10 N
    E. 10 N

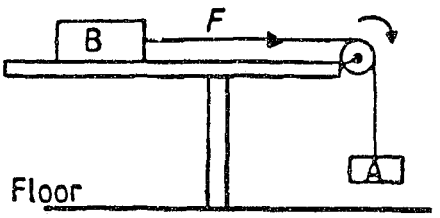
SOURCE: #'s 16 & 17 from: Moolla, M. (1989)

In both items a choice of Option A would have been taken by the source author (Moolla, 1989) as an indication that the interviewee held the misconception that the force of gravity increases with altitude. In both cases, Interviewee 7 repudiated his original choices in the interview and showed that he was well aware of the correct relationship between weight and altitude, even down to the fact that the increases in altitude described in the two items would produce negligible decreases in weight. Unfortunately he could not explain why he had made his original choices, thus for these two items the interviewee presented false positives of unknown origin.

In ITEM 18, Interviewee 7, like Interviewees 8 and 9, interpreted the question as asking for the origin of the force.

18. In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by

A. Block A
B. The earth
C. The string
D. The table
E. The pulley



SOURCE: # 1 from: Helm, (1978) & (1980), also used in Ivowi, (1984)

His choice of Option B is thus not evidence of a misconception as he was able to demonstrate good understanding of the roles played by the various components of the system depicted. In particular he showed recognition that the string provides a link between falling block A and sliding block B and thus transmits the force from A to B. This is an alternative interpretation of what the question is asking for and thus rates as a false positive of language origin.

Like interviewee 8, Interviewee 7 presented false positives definitely attributable to language. While the number involved is smaller, this interviewee's data further weakens the case for the validity of the multiple choice question.

d) Interviewee 5

Interviewee 5 presented two un-targeted misconceptions, one of which emerged five times in the course of his interview.

In ITEM 4, he selected the correct option, C, and confirmed in the interview that he'd made this choice according to correct reasoning.

4. A stone falling from the roof of a single story building to the surface of the earth;

   A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
   B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
   C. speeds up because of the constant gravitational force acting on it.
   D. falls because of the intrinsic tendency of all objects to fall toward the earth.
   E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

SOURCE: # 17 from: Hestenes, D, Wells, M. and Swackhammer, G (1992).

However, when explaining why he had not chosen Option E, he showed agreement for the option statement and thus revealed a belief that air pressure acts downwards and assists gravity in causing a falling object to accelerate:

"*I think it could also be E, um because it does fall because of gravity, - mainly because of gravity, not really because of air pressure .. I suppose air pressure does push down - down on it, so that .. can also be a possibility.*"

Although this misconception was specifically targeted by the item, the interviewee's choice of the correct option was not rated as a false negative because of his ability to justify his choice of Option C as his answer.

The misconceptions targeted by ITEM 9 involve beliefs that i) a resultant force is necessary to cause uniform motion (Option A); ii) that an 'active' force is necessary for motion (Option D) and iii) that air pressure acts downwards and assists gravity in causing downward movement. (Hestenes et al, 1992)
Interviewee 5 chose two options in the written test, Option B (the correct option) and Option D. When asked about his choice of Option B, the interviewee was able to give good account of himself but when attempting to justify his liking for Option D, he revealed an interesting maverick interpretation: to this interviewee, the phrase 'the force of the cable' meant 'breaking strain'. Having said: "*.. the shortening of the*

cable will lift the elevator but the force of the cable can't", this interviewee was then asked to explain what he meant by `the force of the cable', to which he replied:

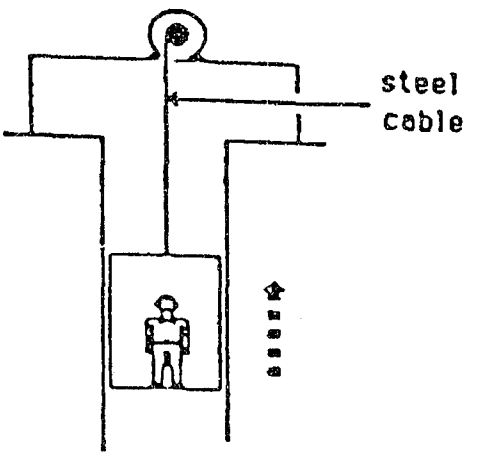
"*Okay, the - the strength of the cable, basically with which .. the force of the cable relative to the .. the elevator, .. the elevator's a certain weight and the cable will be able to resist that weight, it won't break.*"

This definitely rates as language confusion; apart from the novel interpretation, the text of Option D was actually misread. It states: "*the force being exerted on the elevator by the cable*" (Hestenes et al, 1992, p 156) and not "*the force of the cable*" as the interviewee said. There would also have been a false positive rating had the interviewee not chosen Option B in tandem with Option D.

* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

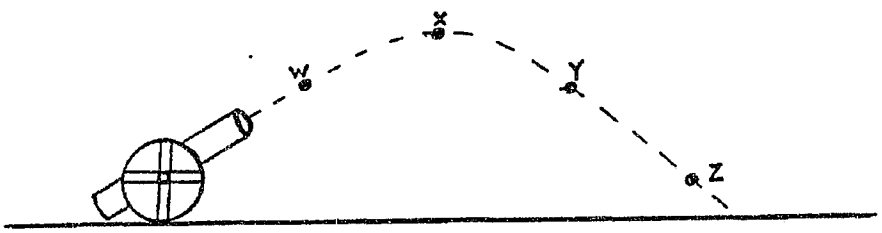


SOURCE: #18 from: Hestenes, D., Wells, M. and Swackhammer, G. (1992)

The un-targeted misconception arose when the interviewee was asked to explain why he had not chosen Option E, at which point he once again showed agreement with the notion of `air pressure assisted gravity' as he had in Item 4.

In ITEM 13, the interviewee chose Option D as his answer.

A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball.
[Assume that there is no friction involved.]



13. At which of the points mentioned in the diagram is the effect of gravity the greatest?

A. W
B. X
C. Y
D. Z
E. The effect of gravity is the same at all four points.

SOURCE: #9 from: Moolla, M. (1989)

When asked to justify his choice Interviewee 5 did not relate gravity to altitude. Instead his answer was suggestive of the notion of impetus somehow impeding the action of gravity and that as the impetus fades away, gravity is increasingly permitted to act on a projectile:

"*Because it"s lost most of its initial force from the .. cannon so it doesn"t act against gravity ..*"

As the impetus misconception was not targeted by this item, this response was rated as indicative of an un-targeted misconception.

In ITEM 16, this interviewee exhibited a false positive of language origin as well as an un-targeted misconception.

The diagram shows an object hanging on a spring balance at sea level.

The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

    A. 30 N
    B. slightly more than 20 N
    C. exactly 20 N
    D. slightly less than 20 N
    E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

    A. 30 N
    B. greater than in Q 16 but less than 30 N
    C. exactly 20 N
    D. less than in Q 16 but greater than 10 N
    E. 10 N

SOURCE: #"s 16 & 17 from: Moolla, M. (1989)

The interviewee's choice for ITEM 16 was Option B which, according to the source author (Moolla 1989), would indicate a misconception in which the force of gravity increases - rather than decreases - with altitude. He began his justification by

stating that he had misread the question and had reasoned as if there had been a decrease in altitude. He then said that he would have chosen Option D - the source author"s `correct" answer - had he not misread the question. His choice of Option B can thus be regarded as a definite false positive of language origin. Further comments in clarification revealed yet again the un-targeted misconception that air pressure acts downwards and assists gravity:

"*.. if you have less air pressure there would be .. less - less of downward force on it so the measurements .. the measurements would be different.*"

The same reasoning was then also used to justify his choice of Option D for ITEM 17. Option D was the source author's correct answer for this item (Moolla 1989) and so without an interview the misconception would not have been uncovered. This specific misconception was not targeted by either of these two items and so was rated as an un-targeted misconception in both cases.

According to the source author a choice of Option C in ITEM 20 was evidence of an "*inability to identify forces*" (Jordan, 1995, p 39).

20. Which one of the following assertions concerning an astronaut standing on the moon, is true?

    A. The astronaut experiences no force, because there is not an atmosphere.
    B. The astronaut experiences no force, because only bodies near the earth are attracted by gravitation.
    C. The astronaut only experiences a downward force as a result of the moon,s gravitational attraction.
    D. The astronaut experiences a downward gravitational force and an upward force exerted by the moon"s surface.
    E. The astronaut only experiences an upward force exerted by the moon,s surface.

SOURCE: #5 from: Jordan, (1995)

When questioned about his choice the interviewee gave no sign that he had any awareness of the necessity of an upward force exerted on his feet by the moon"s surface, saying that:

[there were] "*no other forces acting on him, there"s no air pressure or - or anything like that, so .. that* [i.e. gravity] *should be the only force acting upon him.*"
I would have been inclined to describe this as an incomplete understanding of Newton"s third law, rather than the rather vague description of the `misconception" given by the source author.

One of the target misconceptions for this item was the notion that an atmosphere is somehow a necessary condition for gravity. As a probe for this misconception, the interviewee was asked his opinion of Option A. There was no sign that Interviewee 5 entertained any such notion, instead his reply revealed yet again that he believed that air pressure acts downwards and in so doing, assists gravity. In the context of this item, this is an un-targeted misconception as it was not mentioned by the source author.
The repeated emergence of this misconception suggests quite strongly that it is firmly entrenched in this interviewee"s world view.

The significance of the results presented above will be discussed in the next chapter. At this stage it will be sufficient to say that the interview data show that both `wrong" and `right" answers were chosen by the interviewees for a far greater variety of reasons than was considered by the authors of the articles from which the questions were drawn. It would thus be simplistic to conclude from an `incorrect" answer that a subject held some misconception or from a `correct" answer that he or she did not.

CHAPTER 6: DISCUSSION AND CONCLUSIONS

6.1 DISCUSSION

6.1.1 POINTS OF INTEREST ARISING FROM THE ANALYSIS OF THE DATA

a) Preamble

The results presented in the previous chapter were described on several levels, the description of the data categories being intended merely to show what sorts of data were identifiable in the interview transcripts. These data categories and their qualifiers were then presented in tabular form in Table 1, (p 60) which shows what data category was identified during which interviewee and against which item. No discussion of these presentations of the data will be entered into here as the figures in Table 2 and the subsequent discussions of the data categories and of the individual interviewees are of much more interest with respect to the hypothesis being tested.

b) Table 2

The figures in Table 2 (p 61) cannot be regarded as statistically significant or as indicative of the situation in the general population because none of the usual criteria for statistical validity were observed - the sample was too small, not randomly selected, etc. They do, however represent a condensation of the data into a form from which conclusions can more readily be drawn than in the preceding presentations. The percentages in the last row of the table can be regarded as a rough indication of how often the data categories presented here were revealed during the interviews for this sample of subjects.

If this is accepted, the following points are apparent:

Firstly, false positives (FP) occured more often than target misconceptions (TM): 23.5% vs 16%.

Secondly, false positives that could be linked to language problems (FP/L) occurred almost as often as target misconceptions (TM): 15.5% vs 16%.

Thirdly, results not anticipated by the original researchers, i.e. false positives, un-targeted misconceptions and false negatives (FP, UM & FN), together occurred more often than anticipated results; i.e. target misconceptions and no misconceptions (TM & NM): 35.5% vs 28%. While the latter figure (28%) may seem reminiscent of Yarroch's `Coefficient of Item Validity', (Yarroch, 1991) it must be pointed out that it is not: even though the data categories of target misconception and no misconception do correspond with his `correct for the correct reason and incorrect for the correct reason', Yarroch's coefficient was meant to apply to an individual item rather than to several items collectively. Nevertheless it does seem reasonable to at least suggest that many of the twenty items used in the written test in this study do perhaps have a low level of item validity. Item 18, for example was answered `correctly for the correct reason' only by one subject. All eight of the other subjects demonstrated false positives, seven of which were linked to language problems, i.e. their answers were `incorrect for the incorrect reason'. It would surely not be far-fetched to imagine that a proper calculation of item 18's coefficient of item validity would yield a fairly low score.

Fourthly, false negatives (FN) occurred rarely, in fact being demonstrated only once.

It can therefore be seen that, although the items used in this study were chosen precisely because it was thought that they were open to mis-interpretation, conclusions drawn from published studies in which multiple choice questionnaires were used, should be treated with caution.

c) The individual interviewees

The interviewees dealt with in this section were selected because each illustrated particularly well the point that subjects do not necessarily answer questions in a particular way, whether correctly or incorrectly, for the `right reason' (Yarroch, 1991).

Interviewee 9 exhibited the highest number of false positives in the group. In nine cases (out of twenty items) his incorrect responses to the written test were rated as definite false positives and in only two were target misconceptions definitely identified; i.e. he answered questions incorrectly for the `wrong' reason more than three times more often than for the `right' reason.

Interviewees 7 and 8 exhibited high numbers of false positives that could be linked to language. For Interviewee 7, three out of his five false positives were language based and for Interviewee 8, six of his seven false positives were linked to language. These two interviewees present sufficient evidence by themselves to confirm that language is a confounding variable.

Interviewee 5 repeatedly revealed an un-targeted misconception in his interview. The repetition several times of this data category makes it difficult to doubt, not only that the interviewee really held it but also that it is a reproducible phemonenon.

Each of these interviewees chose answers in this multiple choice test for reasons that were not anticipated by the authors of the source articles from which the items were drawn. These `un-anticipated' reasons include the interference of language problems in the interviewee's reasoning.

6.2 LIMITATIONS

Firstly, this study was purely qualitative and thus no claims can be made regarding the extent of the interference of language with the diagnostic process, either for the population as a whole or for any individual subject. It has only been proven that

such interference did occur, in this study, with this sample and this set of questions, which after all were specifically selected for their 'interpretability'. While language could perhaps be expected to play a role as a confounding variable in the original instruments from which they were selected, or in any other similar instrument; it would certainly be to a lesser degree.

On the other hand, the questions selected for this study were not wildly atypical, nor were they selected exclusively from poorly conducted studies. The questions originating from Hestenes et al (1992 a & b) feature prominently in my questionnaire and were subjected, according to Hestenes et al (1992 a & b) to a long and rigorous process of validation.

It would thus be unreasonable to insist that language interference, of the type that I have demonstrated, could not be expected to occur to some extent in any misconception study using multiple choice questions as the principal diagnostic tool.

Secondly, the questions that this study raises concerning the validity of using purely written, multiple choice tests for the diagnosis of misconceptions must logically apply also to the use of interviews, because in both cases language the only available interface between the thoughts of the subject and the thoughts of the researcher. Considering the pivotal role of the interview in this study, this could be seen as a major weakness unless it is put into perspective. While it is possible that some of the results were the artifacts of my own interpretation (or misinterpretation) of the interview data, I am confident that it would not have been possible to produce quite so many instances of the data categories by creative interpretation. I have no doubt that conclusions reached as a result of a subject's responses to extensive cross-questioning during an interview, while perhaps not absolutely valid, may at least be regarded with much greater confidence than conclusions (which are perhaps better described as assumptions) drawn simply on the basis of a subject's choices in a multiple choice test. According to Posner and Gertzog (1982), an interview provides "*a more valid and 'revealing' indicator of a child's cognitive structure than selection- or production-type written assessment instruments*". (p 199)

6.3 IMPLICATIONS

6.3.1 GENERAL

The results of this study indicate that language problems do sometimes masquerade as misconceptions. This has a very serious implication concerning remediation. If a student is found to be answering questions incorrectly, it could be counterproductive to simply jump to the conclusion that true misconceptions are held. Remediation of true misconceptions demands conceptual change strategies, which would be unproductive if the problem were not one of conception. This may be one reason why misconceptions have so often been shown to be resistant to change. Furthermore, it would be reasonable to state that language must now assume an even greater importance for Science Education than it has hitherto had. Not only must language become a matter for consideration in diagnostic and remedial situations, as an alternative or adjunct to conceptual change, but the role of language during instruction must be carefully examined.

6.3.2 FOR FURTHER RESEARCH

While the results of this study do support the contention that language plays a role as a confounding variable in the diagnosis of misconceptions, they give no indication of the extent of the problem, as this was a purely qualitative study. The following questions have not been answered and could form a basis for further study:

i) What is the extent of language interference in the diagnosis of misconceptions in first language speakers?

ii) Can the same effect also be demonstrated with second language speakers?

iii) If so, what is the extent of language interference in the diagnosis of

misconceptions in second language speakers?

iv) Assuming a 'yes' answer to question ii), how do the answers to questions i) and iii) compare?

v) Assuming a 'yes' answer to question ii), in what qualitative ways can the language interference in first language speakers be compared with that of second language speakers?

vi) Can language interference in the diagnosis of misconceptions be demonstrated in languages other than English; a) with first language speakers, b) with second language speakers?

vii) Assuming a 'yes' answer to either a) or b) of question vi), what is the extent of the interference?

6.4 FINAL CONCLUSION

The hypothesis that language plays a role in the diagnosis of misconceptions has been confirmed in that the null form of the hypothesis, which was tested in this study has undoubtedly been rejected. According to Popper (1934/1959), a single contrary instance is sufficient to negate a universal statement provided that the contrary instance is (at least) in principle reproducible. In this study there were no fewer than 35 instances where definite evidence of language interference arose during the interviews. Of these, 28 were instances where the language interference gave rise to false positives. This study thus provides a good deal more than just the single contrary instance needed.

It can be concluded therefore, that language did play a role as a confounding variable in this study.

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APPENDIX 1:
SAMPLE QUESTIONNAIRE

PHYSICS RESEARCH QUESTIONNAIRE

INFORMATION AND INSTRUCTIONS

This questionnaire is part of a research study which investigates some aspects of multiple choice questions that have been used in other studies in science education.

Further details about this study will be revealed to you and your science teacher once the results have been analysed and may be of value to you in your own studies.

Please answer the questions as best you can on the answer sheet overleaf.

Answer by crossing out the letter that represents the answer of your choice.
If you wish to alter a choice, circle the letter you have crossed out and then cross out the letter you prefer. Please do not erase any answers.

CONFIDENTIALITY:

Your name and the name of the school will be kept strictly confidential and will not in any way be linked with the results of this study should they be published.

(The biographical data below is only needed in case I want to interview you.)

BIOGRAPHICAL DATA

NAME: _____

AGE: _____

FIRST LANGUAGE: _____

OTHER LANGUAGES: _____

FORM: _____

SCHOOL: _____

GRADE: (Standard or Higher) _____

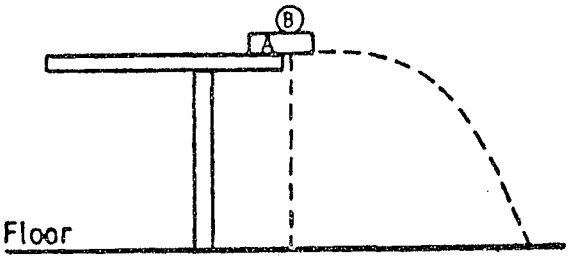
ANSWER SHEET

CROSS OUT THE LETTER REPRESENTING THE ANSWER OF YOUR CHOICE;
ONLY RING THE LETTERS IF YOU WANT TO CHANGE A CHOICE.

1.		a		b		c		d		e			
2.		a		b		c		d		e			
3.		a		b		c		d		e			
4.		a		b		c		d		e			
5.		a		b		c		d		e			
6.		a		b		c		d		e			
7.		a		b		c		d		e			
8.		a		b		c		d		e			
9.		a		b		c		d		e			
10.		a		b		c		d		e			
11.		a		b		c		d		e			
12.		a		b		c		d		e			
13.		a		b		c		d		e			
14.		a		b		c		d		e			
15.		a		b		c		d		e			
16.		a		b		c		d		e			
17.		a		b		c		d		e			
18.		a		b		c		d		e			
19.		a		b		c		d		e			
20.		a		b		c		d		e			

PHYSICS RESEARCH QUESTIONNAIRE

1.. The diagram shows a body B resting on another body A at the edge of a table. If A is given a sharp push such that B drops vertically downward as A is projected off the table with a horizontal velocity, which body reaches the floor first and why?



A. B reaches the floor first because it is acted on directly by gravity.
B. A reaches the floor first because it is given a finite initial velocity.
C. They both reach the floor at the same time because they have the same downward acceleration towards the floor.
D. A reaches the floor first because it travels through a shorter distance to the floor.
E. They both reach the floor at the same time because they accelerated equally downward with the same initial velocity.

2.. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box

A. If the force applied to the box is doubled, the speed of the box will increase to 8.0 m/s.
B. The amount of force applied to move the box at a constant speed must be more than its weight.
C. The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
D. The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
E. There is a force being applied to the box to make it move but the external forces such as friction are not 'real' forces they just resist motion.

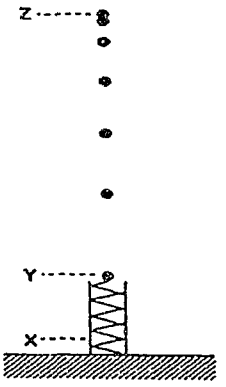
3.. If the force being applied to the box in the preceding problem (A large box is being pushed across the floor at a constant speed of 4.0 m/s.) is suddenly discontinued, the box will;

A. stop suddenly.
B. continue at a constant speed for a very short period of time and then slow to a stop.
C. immediately start slowing to a stop.
D. continue at a constant velocity.
E. increase speed for a very short period of time, then start slowing to a stop.

4.. A stone falling from the roof of a single story building to the surface of the earth;

A. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
B. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational pull.
C. speeds up because of the constant gravitational force acting on it.
D. falls because of the intrinsic tendency of all objects to fall toward the earth.
E. falls because of a combination of the force of gravity and the air pressure pushing it downward.

* Refer to the diagram in the right margin to answer the following question.

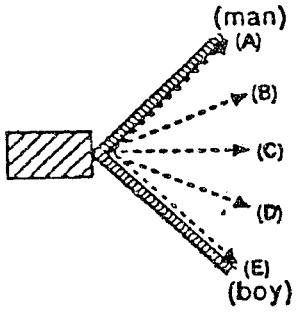


The figure represents a multiflash photograph of a small steel ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, reaches its highest point at the point marked Z.

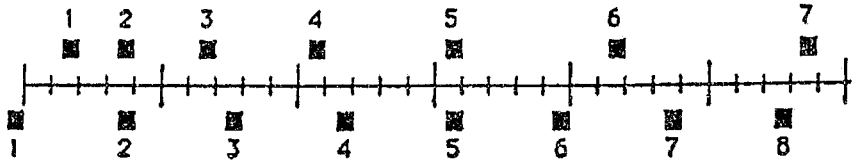
5. Assuming that the air resistance was negligible;

A. The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring)
B. The acceleration of the ball was decreasing on its way from point Y to point Z.
C. The acceleration of the ball was zero at point Z.
D. All of the above responses are correct.
E. The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

6.. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as shown on the diagram to the right. Which of the indicated paths (A - E) would most likely correspond to the path of the crate as they pull it along?



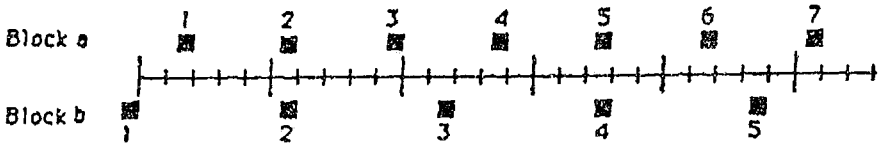
* The positions of two blocks at successive 0.02 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



7.. Do the blocks ever have the same speed?

A. No.
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instant 2 and 5.
E. Yes at some time during interval 3 to 4.

* The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



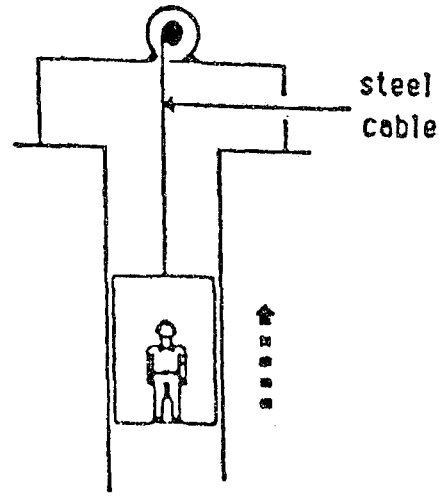
8.. The acceleration of the blocks are related as follows:

A. acceleration of 'a' > acceleration of 'b'.
B. acceleration of 'a' = acceleration 'b' > 0.
C. acceleration of 'b' > acceleration 'a'.
D. acceleration of 'b' = acceleration 'a' = 0.
E. not enough information to answer.

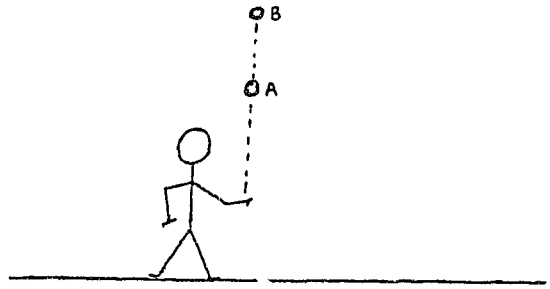
* When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

9.. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving at a constant velocity;

A. the upward force on the elevator by the cable is greater than the downward force of gravity.
B. the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
C. the upward force on the elevator by the cable is less than the down ward force of gravity.
D. it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
E. the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



An object is thrown straight up into the air. It leaves the thrower's hand, goes up to B and then comes back down to the thrower's hand. [Assume that there is no friction involved]



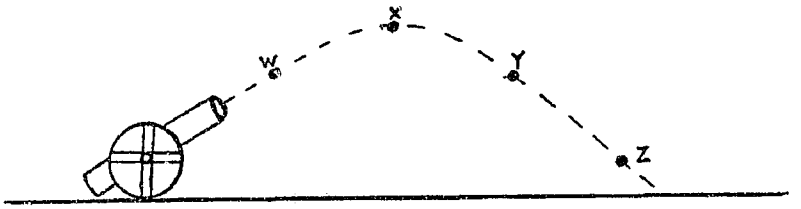
10. While the object is moving upwards, the direction of the force on it is

A. upwards.
B. downwards.
C. to the left.
D. to the right.
E. There is no force acting on it.

11. In the real-world situation, which of the following statement/s is/are correct.

A. When the object is moving upwards, friction acts downwards on it.
B. When the object is moving downwards, friction acts upwards on it.
C. The time taken by the object to go up would be longer.
D. The maximum height reached by the object would be smaller.
E. The object will take longer to come back to the thrower's hand.

A cannon ball is fired from a cannon. Points W, X, Y and Z are four points on the path of the cannon ball.
[Assume that there is no friction involved.]



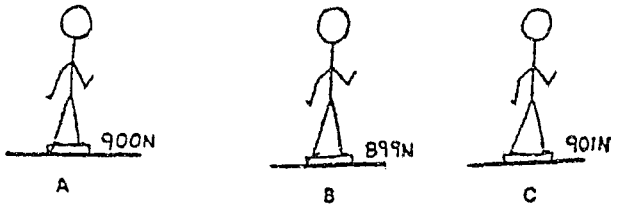
12. At which of the points mentioned in the diagram is the force on the cannon-ball the greatest?

A. W
B. X
C. Y
D. Z
E. The force is the same at all four points.

13. At which of the points mentioned in the diagram is the effect of gravity the greatest?

A. W
B. X
C. Y
D. Z
E. The effect of gravity is the same at all four points.

Three men of equal masses are each standing on stationary scales at different places on earth. The numbers represent their weight as shown by the scale.



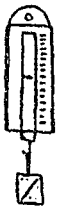
14. Who experiences the greatest gravitational force?

A. A.
B. B.
C. C.
D. They all feel an equal gravitational force.
E. We cannot say because we need more data.

15. Who is closer to the earths centre?

A. A.
B. B.
C. C.
D. They are all the same distance from the earth's centre.
E. We cannot say because we need more data.

The diagram shows an object hanging on a spring balance at sea level.



The reading on the spring-balance is 20 N.

16. What is the most likely reading on the spring-balance if the apparatus is taken up to the top of a building in Durban that is 50 m tall?

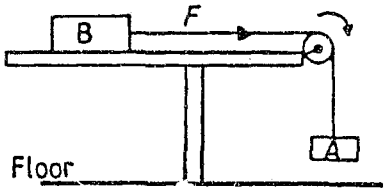
A. 30 N
B. slightly more than 20 N
C. exactly 20 N
D. slightly less than 20 N
E. 10 N

17. What is the most likely reading on the spring-balance if the apparatus is taken to the top of Mount Everest which is 8800 m above sea-level?

A. 30 N
B. greater than in Q 16 but less than 30 N
C. exactly 20 N
D. less than in Q 16 but greater than 10 N
E. 10 N

18. In the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by

A. Block A
B. The earth
C. The string
D. The table
E. The pulley



19. Which one of the following may not be a true statement about a body in uniform motion?

A. its velocity may be zero.
B. its velocity may be constant.
C. its acceleration may be zero.
D. its acceleration may be constant.
E. its velocity may be varying.

20. Which one of the following assertions concerning an astronaut standing on the moon, is true?

A. The astronaut experiences no force, because there is not an atmosphere.
B. The astronaut experiences no force, because only bodies near the earth are attracted by gravitation.
C. The astronaut only experiences a downward force as a result of the moon,s gravitational attraction.
D. The astronaut experiences a downward gravitational force and an upward force exerted by the moon's surface.
E. The astronaut only experiences an upward force exerted by the moon,s surface.

APPENDIX 2:
SCHEDULE OF TARGET MISCONCEPTIONS

INTERPRETATION: Capitalised text expresses the conclusion drawn by the source author in the case of choice of an option by a subject, lower case text expresses alternative interpretation(s) of the same outcome.

Item #	OPTION	DIAGNOSIS ACCORDING TO SOURCE AUTHOR/ other possible interpretations.
1	A	CONFUSING HORIZONTAL AND VERTICAL INITIAL VELOCITIES, / gravity's effect somehow impaired by horizontal velocity.
	B	NOT STATED, /
	C	FAILING TO TAKE INITIAL STATE OF OBJECT INTO ACCOUNT WHEN PREDICTING MOTION/
	D	NOT STATED/ correct answer if subject takes into account fact that diagram shows object B clearly above object A, and thus B has farther to fall.
	E	CORRECT ANSWER AS INITIAL STATE OF BOTH OBJECTS AS WELL AS THEIR ACCELERATION ARE TAKEN INTO ACCOUNT.
2	A	VELOCITY PROPORTIONAL TO APPLIED FORCE
	B	MOTION WHEN FORCE OVERCOMES RESISTANCE
	C	CORRECT ANSWER
	D	MOTION WHEN FORCE OVERCOMES RESISTANCE
	E	RESISTANCE OPPOSES FORCE/IMPETUS
3	A	MASS MAKES THINGS STOP/MOTION IMPLIES ACTIVE FORCE
	B	IMPETUS DISSIPATION/ MASS MAKES THINGS STOP
	C	CORRECT ANSWER
	D	IMPETUS SUPPLIED BY HIT
	E	GRADUAL/DELAYED IMPETUS BUILD-UP
4	A	FORCE CAUSES ACCELERATION TO TERMINAL VELOCITY
	B	GRAVITY INCREASES AS OBJECTS FALL/ ACCELERATION IMPLIES INCREASING FORCE.
	C	CORRECT ANSWER
	D	GRAVITY INTRINSIC TO MASS/ Aristotelian notion of 'rightful place'.
	E	AIR PRESSURE-ASSISTED GRAVITY
5	A	NOT SPECIFIED/ Velocity-acceleration un-discriminated / failure to relate acceleration to resultant force; lack of knowledge of Hooke's law.
	B	NOT SPECIFIED/Velocity-acceleration un-discriminated conceptually / Velocity-acceleration un-discriminated verbally.
	C	NOT SPECIFIED/Velocity-acceleration un-discriminated conceptually / Velocity-acceleration un-discriminated verbally.
	D	NOT SPECIFIED/Velocity-acceleration un-discriminated conceptually / Velocity-acceleration un-discriminated verbally.
	E	CORRECT ANSWER

6	A	LARGEST FORCE DETERMINES MOTION
	B	CORRECT ANSWER
	C	FORCE COMPROMISE DETERMINES MOTION
	D	FORCE COMPROMISE DETERMINES MOTION
	E	NOT SPECIFIED
7	A	VELOCITY-ACCELERATION UN-DISCRIMINATED
	B	POSITION-VELOCITY UN-DISCRIMINATED
	C	POSITION-VELOCITY UN-DISCRIMINATED
	D	POSITION-VELOCITY UN-DISCRIMINATED
	E	CORRECT ANSWER
8	A	NOT SPECIFIED
	B	VELOCITY-ACCELERATION UN-DISCRIMINATED
	C	VELOCITY-ACCELERATION UN-DISCRIMINATED
	D	CORRECT ANSWER
	E	NOT SPECIFIED
9	A	LARGEST FORCE DETERMINES MOTION
	B	CORRECT ANSWER
	C	NOT SPECIFIED
	D	ONLY ACTIVE AGENTS EXERT FORCES
	E	AIR PRESSURE-ASSISTED GRAVITY / LARGEST FORCE DETERMINES MOTION
10	A	GRAVITY DOES NOT ACT ON AN UPWARD-MOVING OBJECT
	B	CORRECT ANSWER
	C	NOT SPECIFIED
	D	NOT SPECIFIED
	E	GRAVITY DOES NOT ACT ON AN UPWARD-MOVING OBJECT
11	A	CORRECT ANSWER
	B	CORRECT ANSWER
	C	NOT SPECIFIED
	D	CORRECT ANSWER
	E	CORRECT ANSWER

12	A	IMPETUS: GREATEST CLOSEST TO MOST RECENT APPLICATION OF PUSHING FORCE / NEED FOR FORCE IN DIRECTION OF MOTION.
	B	FORCE OF GRAVITY INCREASES WITH ALTITUDE /
	C	NOT SPECIFIED / possibly as below.
	D	VELOCITY PROPORTIONAL TO APPLIED FORCE /
	E	CORRECT ANSWER
13	A	FORCE OF GRAVITY VARIES WITH ALTITUDE.
	B	FORCE OF GRAVITY VARIES (INCREASES) WITH ALTITUDE.
	C	FORCE OF GRAVITY VARIES WITH ALTITUDE.
	D	FORCE OF GRAVITY VARIES (DECREASES) WITH ALTITUDE.
	E	CORRECT ANSWER.
14	A	NOT SPECIFIED
	B	[CORRECT ANSWER]/ WEIGHT DECREASES AS FORCE OF GRAVITY INCREASES /
	C	correct answer
	D	GRAVITATIONAL FORCE CONFUSED WITH GRAVITATIONAL ACCELERATION / force of gravity not same as weight.
	E	NOT SPECIFIED
15	A	NOT SPECIFIED
	B	[CORRECT ANSWER] / NOT SPECIFIED
	C	correct answer
	D	FORCE OF GRAVITY DOES NOT VARY WITH ALTITUDE / force of gravity not same as weight.
	E	NOT SPECIFIED
16	A	FORCE OF GRAVITY INCREASES WITH ALTITUDE
	B	FORCE OF GRAVITY INCREASES WITH ALTITUDE
	C	FORCE OF GRAVITY DOES NOT VARY WITH ALTITUDE / correct answer; good insight into relationship between a 50 m change in altitude and the earth's radius and/or accuracy of spring balances.
	D	CORRECT ANSWER / lack of insight into how much the force of gravity varies with altitude, the comparison between a 50 m change in altitude and the earth's radius and/or accuracy of spring balances.
	E	NOT SPECIFIED / extreme lack of insight into how much the force of gravity varies with altitude, the comparison between a 50 m change in altitude and the earth's radius and/or accuracy of spring balances.

17	A	FORCE OF GRAVITY INCREASES WITH ALTITUDE
	B	FORCE OF GRAVITY INCREASES WITH ALTITUDE
	C	correct answer / FORCE OF GRAVITY DOES NOT VARY WITH ALTITUDE
	D	NOT SPECIFIED / extreme lack of insight into how much the force of gravity varies with altitude, the comparison between an 8 800 m change in altitude and the earth's radius and/or accuracy of spring balances.
	E	CORRECT ANSWER (!) / extreme lack of insight into how much the force of gravity varies with altitude, the comparison between an 8 800 m change in altitude and the earth's radius and/or accuracy of spring balances.
18	A	FAILURE TO RECOGNISE THAT THE AGENT IN CONTACT MUST EXERT A CONTACT FORCE / FAILURE TO DISTINGUISH BETWEEN CONTACT FORCES AND NON-CONTACT FORCES / interpretation of the question as asking for the origin of the force exerted.
	B	FAILURE TO RECOGNISE THAT THE AGENT IN CONTACT MUST EXERT A CONTACT FORCE / FAILURE TO DISTINGUISH BETWEEN CONTACT FORCES AND NON-CONTACT FORCES / interpretation of the question as asking for the origin of the force exerted.
	C	CORRECT ANSWER
	D	NOT SPECIFIED / possible misinterpretation of question as asking for either frictional force on B or force by table pushing upwards on B.
	E	NOT SPECIFIED
19	A	LACK OF RECOGNITION THAT ZERO VELOCITY IS A SPECIAL CASE OF UNIFORM MOTION / interpretation of zero velocity as complete lack of motion & thus not qualifying as uniform motion.
	B	UNIFORM MOTION NOT DEFINED AS CONSTANT VELOCITY / interpretational difficulty arising from the negative phrasing of the question.
	C	UNIFORM MOTION NOT DEFINED AS CONSTANT VELOCITY / interpretational difficulty arising from the negative phrasing of the question.
	D	UNIFORM MOTION NOT DEFINED AS CONSTANT VELOCITY / recognition that the acceleration could have a constant value of zero, coupled with interpreting the phrase 'may not be a true statement' as meaning 'the possibility exists that it is not a true statement'.
	E	CORRECT ANSWER
20	A	BELIEF THAT THE ATMOSPHERE CAUSES GRAVITY, HENCE, NO ATMOSPHERE: NO GRAVITY / a certain minimum force of gravity is necessary for an atmosphere to exist, hence lack of an atmosphere might be taken as evidence of the lack of gravity.
	B	GRAVITY EXISTS ONLY ON OR NEAR THE EARTH.
	C	INABILITY TO IDENTIFY FORCES / subject may simply have read no further, having found an option that sounded (at least partially) correct.
	D	CORRECT ANSWER
	E	INABILITY TO IDENTIFY FORCES.

APPENDIX 3a: INTERVIEW TRANSCRIPT

	MAIN INTERVIEW EIGHT	
Q #	**STATEMENT**	**COMMENTS**
1	Q: Neil um, . . first of all, in question one, the answer you chose was C, could you explain your reasoning behind that please?	
1	A: Okay, .. in er A, `B reaches the floor first because it is acted on directly by gravity', .. er well they're both .. the reasoning behind that was that was that I thought A and B were both acted upon by gravity; um, `A reaches the floor first because it is given a finite initial velocity', I didn't think that was correct at all; C I gave as the correct answer because they do both have the same downward acceleration, as the force of gravity on both of them is equal, no matter .. how heavy or - or light the object is.	Correct prediction of outcome (with some licence!) but with the less favourable justification given. Rejections of options A and B.
1	Q: M hm, .. and what about E, by comparison with C?	
1	A: Basically the same thing, .. but // if there's constant .. acceleration, then the .. initial velocity's zero.	
1	Q: Okay, so why didn't you choose E instead of C?	
1	A: I just found C to be more correct, I didn't quite agree with E.	
1	Q: What was - what do you find wrong with E?	
1	A: Hm! .. they're both the same actually.	

	MAIN INTERVIEW EIGHT		
Q#	**STATEMENT**		**COMMENTS**
1	Q:	You say they're both the same ..	
1	A:	They both have the same reasoning, C and E, both initial velocity - the initial velocity of A and B were both zero, 'cause they were stationary and then the force was applied to A.	Seems not to have noticed that initial velocity is not mentioned in E; appears to take this `as read'.
1	Q:	Okay, and how about D?	
1	A:	Oh well, it doesn't travel a shorter distance to the floor because they're both the same height above the floor, in fact it might have travelled a longer distance getting to the floor because it went out first and then came down, .. // displacement doesn't equal to B.	Higher altitude of object B unnoticed. No misconception here according to original author's criteria; fails to choose `correct' option because of `creative reading'.
3	Q:	Okay, then let's skip to s.. number three, .. which speaks of a box being pushed across the floor and so relates to the same situation described in question two. And in this particular question you first chose E and then you reconsidered and then chose C, can you tell us what .. was behind that?	
3	A:	The reason actually was I put - I put E for three, meaning to put it for two, .. that's why - that's why I circled it as incorrect.	Orientation error
3	Q:	Oh so it was purely ..	
3	A:	A mistake, I /// on behalf of the answer but .. not looking at the question she - the answer sheet.	

	MAIN INTERVIEW EIGHT	
Q#	**STATEMENT**	**COMMENTS**
3	Q: Okay so it actually had nothing to do with - with three at all, it was just er .. // alright then why do you particularly like C?	
3	A: Well I pictured the actual problem inside my head, pushing a box along a floor, and as soon as you stop applying .. the force to it the box starts to slow down and comes to a dead stop anyway, .. so I simply pictured in my head as what was happening and that's how I came across C.	Correct answer, correct reasoning.
3	Q: Alright, er what about a few of the other options there, let's start with A?	
3	A: Okay well the box doesn't stop .. dead immediately, it'll carry on for a - a very slight distance because of its momentum; but B, `continue at a constant speed for a very short period of time and then slow to a stop', well it doesn't continue for such a long time, it comes to a slop - a stop almost immediately but not suddenly as in A; `continue at a constant velocity', well there's friction applied to the - the box and th- it'll eventually stop, um well it'll stop immediately and `increase speed for a very short time, then start slowing to a stop', well it wouldn't increase because you don't apply a - a larger force on it, so it would decrease immediately, it would come to a stop.	Shows good insight and good observational ability.
3	Q: Okay, um what er - what sort of box did you picture when you read the question?	
3	A: Er a cardboard box, a wine box or .. grocery box ..	
3	Q: Um empty or full?	
3	A: Emp - er full.	

	MAIN INTERVIEW EIGHT		
Q#	**STATEMENT**		**COMMENTS**
3	Q:	Okay, and then er .. type of floor?	
3	A:	A tiled floor, with a bit of dust - gravel on, something that would er hinder the movement of the box as you pushed it.	No misconception in evidence.
4	Q:	Okay ... right, then number four is the next on my list and er ther again you chose - first of all you chose C and then you changed it to A.	
4	A:	The reason there was I - after I had done .. three and four, I'd realised that I had missed two // everything actually should be moved one up. So that's why there's the same mistake as in .. three where I'd crossed C .. in four, when I should have crossed it in three. It was only in four that I realised that I had .. er .. made the mistake that led up to ..	Orientation error.
4	Q:	Okay fine then um, could you .. // what the answer to ..[4]	
4	A:	Well the stone, as it falls from the roof, starts to accelerate till it's at a constant acceleration so it should be // in the beginning, er .. picks up till it reaches its maximum speed then it starts falling at a constant speed .. the same acceleration.	Subject thinks stone will reach terminal velocity during fall.
4	Q:	What's it that er .. what causes that to happen?	
4	A:	Um, .. which - the force of gravity .. increases - well it doesn't increase but it er ..it causes the stone to increase till it reaches the maximum.	
4	Q:	Okay, what particular value concerning the stone increases .. as a result of that .. gravity.	

	MAIN INTERVIEW EIGHT		
Q#	STATEMENT		COMMENTS
4	A:	Er, .. the speed increases until it reaches - until it has reached a constant speed, in metres per second.	
4	Q:	Okay, what .. what is it that er makes .. for that constant speed limit.	Probing for knowledge of the role of air resistance.
4	A:	Well er .. it's - it - equilibrium, um, the rate at which the stone falls is the um - is where it reaches its er terminal velocity, where it er - I don't really remember the exact details, um .. it basically reaches its terminal velocity and I can't remember when it um ..	
4	Q:	But why - why should it reach its terminal velocity?	As above.
4	A:	Because of its weight. But it'll .. well its weight won't really make a difference, just reach it quicker or slower um ..	No evidence of knowledge of the role of air resistance in terminal velocity.
4	Q:	Alright, what sort of a stone did you have in mind when you read the question?	
4	A:	Just an ordinary stone.	
4	Q:	How big?	
4	A:	About .. three centimetres in diameter.	
4	Q:	Approximately: the height of the building in metres?	
4	A:	I'd say about .. about a hundred metres.	Maverick interpretation of meaning of `single story building', makes the choice of A almost reasonable. Could be a reading error: subject might not have noticed `single story'

	MAIN INTERVIEW EIGHT		
Q#	**STATEMENT**		**COMMENTS**
6	Q:	Okay. Alright, and .. then we go to question six; ,.. and in question six, the first thing that intrigues me is that you put a circle around the question number, what is that .. ?	
6	A:	I left it out at first and then came back to it, I wasn't .. don't be too concerned about that.	
6	Q:	Ah, okay, alright and then your choice of C as the answer, please explain your reasoning there.	
6	A:	Well it says `two people, a large man and a boy are pulling as hard as they can on two ropes attached to a crate as shown on the diagram to the right', they don't really give an indication of how hard the man can pull or how hard the boy can pull so, I figured .. I couldn't say it was er choice B where the - the box would be pulled towards the man simply because he's larger or - or because he's stronger, I said C because .. they don't - they don't give you an indication of - if they're pulling at the same - with the same force, of if the man is er stronger than the boy or the boy is stronger than the man, so I said C, it'll go straight forward.	Question fails to convey to subject the meaning intended by the original researcher. Subject's correct reasoning has produced an answer that would be regarded as a misconception by the original researcher. A difinite false positive through a breakdowr in the communication between question and subject, i.e. of linguistic origin.
7	Q:	Okay, um .. then next I'd like to look at number seven and eight, which are .. related to each other although they're not about the same thing; um, you gave E as your answer to number seven.	

	MAIN INTERVIEW EIGHT		
Q#	**STATEMENT**		**COMMENTS**
7	A:	Okay ..// in the upper row of blocks, the block moves from one to two, which has a very small distance between it and then two to three and then from three to four and four to five, increasing the gap all the time; um then in the - the bottom row of blocks, um, one moves till two, has a larger gap than the upper row of blocks from one to two, and then a larger gap from two to three as the upper row, and then at three and four they both move the same - the distance between three and four in the upper row is the same - approximately the same the distance between three and four in the bottom row, which I took to be as er them having the same speed then - travelling at a con- the same speed.	Correct answer, correct justification; no misconception.
8	Q:	Okay, then number eight, your answer there is C.	
8	A:	Er 'the acceleration of B is greater than the acceleration of A', um, well here I thought um, because there's a larger gap between the blocks .. on the bottom row between block one and two, um it's accelerating at a - a faster - faster rate, whereas the upper row: the gaps are .. hm .. the gaps are, between one and two is smaller but I can see here ja .. okay, should be the same .. but um ..	
8	Q:	What should be the same?	
8	A:	The acceleration, because A accelerates - it has a constant acceleration, so it's accelerating at the same time as B, which also has a constant acceleration. So what I thought was the - because the - the gap between the - the blocks on the lower level were greater, it was accelerating at a quicker rate.	Original reasoning: relates gaps between the blocks to acceleration rather than to velocity.

	MAIN INTERVIEW EIGHT		
Q #	STATEMENT		COMMENTS
8	Q:	Okay, what do you think now?	
8	A:	Now I would probably think um .. that the accelerations of both block A and B are the - are the same, because they both move at a constant er .. the gaps between the blocks .. are not equal but are proportional to each other. So on the upper row, one to two is approximately the same as from two to three, from three to four and likewise on B, the - the block - um block B on the lower row, one to two is approximately the same as two to three and three to four; they're both accelerating at the same rate, .. till they reach a constant acceleration.	Has reconsidered, and rejected the reasoning used in his original attempt; now correctly relating gap size to velocity. Final comment mystifying.
8	Q:	Er, which paricular option would you now take as the correct answer?	
8	A:	I'd probably choose D.	Correct answer.
8	Q:	D?	
8	A:	Ja.	
8	Q:	Okay, could you just um .. very briefly just //// behind that?	
8	A:	Well A would probably - A looks like it's travelling .. slower ..	Correct answer.
8	Q:	And what's the evidence you use for that?	
8	A:	Because there's more - there're more, er there're more, the intervals er .. it goes from one to seven in the same distance that B takes from one to - in the same distance as B, but B's from one to five.	Inarticulate but possibly evident of correct reasoning.
18	Q:	Okay, um .. then next on the agenda is number eighteen	

	MAIN INTERVIEW EIGHT		
Q #	**STATEMENT**		**COMMENTS**
18	A:	Well the string is also indirectly er - well the string is directly actually, um affecting the er - affecting B, is pulling B at the same force that er .. A is pulling on the string, that the earth is pulling on A, um .. the table doesn't really exert a force - well doesn't exert the force F, on B and er .. the pulley .. doesn't have much effect on the force F .. but simply makes it easier for the string to - to pull on the force - er on block B. And er block A, is pulling on um block B, which is the force F but it's as a result of this - of the earth's pull on block A, so the earth would be a - would be the more general answer, I thought.	Shows a good grasp of the situation depicted, evidence that there is a distinction between contact and non contact forces in his mind even though he seems to be unfaminiar with the terms. This answer definitely seems to be a false positive of linguistic origin.
19	Q:	Okay, next one on the list is number nineteen, and you chose there, A.	
19	A:	I think that was a bit of a guess! 'Which one of the following may not be a true statement about a body in uniform motion? Its velocity may be zero.' Ja I think I actually guessed that answer.	
19	Q:	Okay, now .. can you try and pinpoint for me what it was that made it necessary for you to guess, I mean ..?	
19	A:	Well I couldn't really decide on which one .. would be correct; 'its velocity may be varying, its acceleration may be constant, its acceleration may be zero, its velocity may be constant, its velocity may be zero. Um, I couldn't really prove to myself that either of them could be false .. or prove that any of then could be true, I chose A.	
19	Q:	Um, what does the term 'unifom motion' mean to you?	

	MAIN INTERVIEW EIGHT		
Q #	STATEMENT		COMMENTS
19	A:	Another thing, sorry, um, about a body in uniform motion, I - I - I heard somewhere that, I dunno where I've read it or I - it just struck me as well, I've seen it somewhere that when body's in uniform motion, its velocity is zero - or its initial velocity is zero.	Further evidence of vague grasp of the terms of the definition.
19	Q:	Okay, as you sit now is there .. have you had any other thoughts about it while you've been sitting there, thinking?	
19	A:	No, I'd still choose A, probably.	
20	Q:	Okay um, let's have a look at number twenty quickly and in number twenty, your choice was E.	
9	A:	`The upward force in the elevator by the cable is greater than the downward force of gravity' .. // in B, `the amount of upward force on the elevator by the cables equal to that of the downward force of gravity' .. um I didn't think that was correct because the .. um it wouldn't really make a difference because there's still the - the .. weight of the man inside, not just the elevator, um which would increase the weight of the - the whole - the elevator, and well, the elevator and the man's weight .. means there's a greater force .. of gravity on it, um, the .. the cable would have to be - well not the cable - ja well the cable - the motor er er the motor's effect on the steel cable, pulling the cable up, pulling the elevator up would have to be greater than its downward force to result in the cable going up; ...	Definite linguistic confusion here: jubject interprets `downward force of gravity' to mean the weight of the elevator excluding its passenger. It could thus be reasonable to choose option A because the force on the elevator by the cable would need to be equal to the combined weight of the elevator plus its occupant. Unfortunately there is no certainty that the subject chose option A on this basis.

	MAIN INTERVIEW EIGHT	
Q#	STATEMENT	COMMENTS
9	.. um then C, `the upward force on the elevator by the cable is less than the downward force of gravity', .. well I thought that would be a bit ridiculous, then it wouldn't - I didn't think it would really be moving up, if the upward force is less than the downward force then it would generally move down and not upwards unless there was something wrong with the cable; and then in D, `it goes up because the cable is being shortened, not because the force being exerted on the elevator by the cable' well the cable doesn't get shorter, it stays the - the same length, .. but it's wound up, // um I thought that was a bit of a .. question but er .. the cable doesn't shorten, it .. it's just the force of the motor .. applied onto the cable that causes the cable to move up, which pulls the elevator up and then in E, `the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity', I just didn't agree with that, .. I found A to be more correct than - than any of the others. elevator up and then in E, `the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity', I just didn't agree with that, .. I found A to be more correct than - than any of the others. elevator up and then in E, `the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity', I just didn't agree with that, .. I found A to be more correct than - than any of the others.	Similarly tantalising glimmers of good reasoning are also in evidence further on; such as his dismissal of the notion that the cable could be `getting shorter'.

	MAIN INTERVIEW EIGHT		
Q#	**STATEMENT**		**COMMENTS**
9	A:	`The upward force on the elevator by the cable is greater than the downward force ..' .. similar to A, except that they're taking into account the air pressure, which I actually didn't think too much about, um I didn't think it would be such a - er such a - a major factor on the elevator that it would er .. cause the - cause the elevator to - to accelerate faster upward or at a slower rate, I didn't think the air pressure would have much to do with it because the elevator doesn't move at such a - a high speed; so the - the air pressure would be minimal on the cable - I mean on the elevator, so I thought that A would be better, I didn't think the air pressure would have much to do with it, .. whereas the force of gravity is the same as in A, and according to me, the most er concerning thing.	Reading error in evidence: He gives reasonable evidence that he understands quite well how air pressure works, shows no evidence of the `air pressure acts downwards' misconception and dismisses the option on the grounds that the effect would be negligible due to the slow speed of the elevator. He seems, however to have entirely missed the fact that the question stem instructs him to regard air resistance as negligible.
9	Q:	What .. what would produce the air pressure, .. referred to in E?	
9	A:	The particles of air .. surrounding the elevator in the shaft.	
9	Q:	Tell me more about it.	
9	A:	Er .. ja well as the elevator moves up, the particles would collide with the elevator, causing it to slow down, but I thought it would be so minimal that it woudn't really make a difference. Um there's not much place for the air - judging by the diagram., there isn't much place where the air can be moved but .. being pushed up .. but um, I still didn't think it would be such a - a major - a major factor on the whole system.	See above. Though it is tempting to dismiss this question as a false positive, the evidence is not strong enough and this must rate as a `no conclusion with evidence of linguistic confusion'.

	MAIN INTERVIEW EIGHT		
Q #	**STATEMENT**		**COMMENTS**
14	Q:	Before you go on, what do you mean by `effect of gravity'?	
14	A:	Well the same as well, effect of gravity as in the downward force or your weight .. that you apply on the earth, um .. I thought it would be the - the it would be the same anywhere on earth - on the surface of the earth. Um ..	Now he states that force of gravity is the same as weight; this seems to be in contradiction with his earlier position.
14	Q:	To make a difference where - that would one have to do?	
14	A:	Well to be .. either closer to the center of the earth or further away from the center, or further away from the earth - the earth's surface.	Now showing good knowledge of the relationship between gravitational force and altitude.
14	Q:	How much?	
14	A:	I would say out of the atmosphere, not - or maybe not so - quite so drastic but .. pretty much .. out of the atmosphere to feel a less - or less of a force of gravity from the earth.	As above. No evidence that he holds the original author's target misconception or even the alternative suggested by me.
15	Q:	Okay, .. alright then .. um just skip - no let's not skip, come to the // in number fifteen, the answer you gave there was C.	

	MAIN INTERVIEW EIGHT		
Q #	**STATEMENT**		**COMMENTS**
15	A:	Ja, I'm still happy with fourteen.	!?
16	Q:	Okay, and number sixteen? The answer you gave to sixteen is C.	
16	A:	I mean going fifty metres up above the earth doesn't make much difference .. of the weight of the - the object hanging on the spring balance, it's still at the same, or more or less the same sea level as the effect of there - the gravity as er .. a very minimal effect, if - if any at all on the object on the spring balance so I took it to be exactly as twenty newtons - being the same as what it was at the bottom of the building - the foot of the building.	Definite false positive: even though somewhat garbled, there is no evidence in this statement that the subject holds the target misconception. No evidence either of linguistic confusion but see comment below.
17	Q:	Okay and then number seventeen? Again you answered C.	
17	A:	Okay well if //// or very accurate, in seventeen, I would have said it would have been .. just less than twenty, nineteen and a half, maybe	Lack of insight into scales in evidence: far too big a difference in readings envisaged.
	END OF INTERVIEW: TAPE EXPIRED		

APPENDIX 3b: INTERVIEW TRANSCRIPT

	MAIN INTERVIEW NINE	
Q#	STATEMENT	COMMENTS
2	Q: Now Jethro, if - we'll kick off with number two, the one about the box being pushed across the floor, and the answer you gave is .. E, could you tell us what .. the reason behind that was?	
2	A: It says: 'there is a force being applied to the box to make it move but the external forces such as friction are not real forces, they just resist motion. I just thought that was the most valid one out of - I // can't really remember it all but .. um .. I started thinking, friction as being a force of course is resisting it .. and well the - the motion obviously .. got past the frictional stage, 'cause if you notice, being able to .. kind of like .. beat it .. being able to push it, um ja // ..	
2	Q: Okay, what do you think they meant, um in option E by the phrase `not real forces'?	
2	A: Well often people like term a force as being a physical movement and with - what's it? the - the floor is re- regarded as the friction .. so a force is kind of usually twer- termed, I suppose in colloquial .. language, er as just like being pushing; well, as the floor is just - helps friction's resistance, it's er not .. physical.	
2	Q: Okay, could you be a little clearer about what, in your mind, you mean by `real force'?	
2	A: Real force? Well `real force' I would regard as .. I er .. in my mind I think it would be something like .. ja a physical movement - or something .. ja projecting.	

	MAIN INTERVIEW NINE	
Q#	**STATEMENT**	**COMMENTS**
2	Q: Okay, what about a few of the other options there? Any of it strike you as paricularly significant and comment-worthy?	
2	A: Um, I suppose A's valid because ... the - the force remains .. ja the frictional force remains the same. Um .. ja B's also .. valid ..	
2	Q: It responds to the voice.	
2	A: Oh really? //// Um what else? /// Ja, D is also valid. // I think I was choosing the most .. er that appealed to me the most, I suppose.	
2	Q: You seem to have skipped C.	
2	A: Er C, Okay, `the amount of force applied .. the frictional force the wh- the speed .. must be equal to the - to the amount of the frictional forces um .. it sounds as though the force being applied is equal to the frictional force.	
2	Q: //// that's what C says.	
2	A: Ja but I thought you always had to get beyond the frictional force being equal to ... so I didn't really regard C as .. an option.	Target misconception for B and D
2	Q: Okay now, you - you did as you went through, say that A, B and C struck you as all being valid so why did you choose E instead of any of the - of those others?	
2	A: I think // what you could only choose was one.	
2	Q: M hm, and if you ... felt free to choose more than one, what would you have done?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
2	A:	I suppose I would have taken A, B, D as well.	
2	Q:	And - and you left C out?	
2	A:	Think so.	
2	Q:	Okay, .. um if you push any object, and you apply to it any force larger than .. frictional forces, how does the object then behave?	
2	A:	Well it depends what if it .. what shape the box is and all, what sort of a box is it, can sort of stutter along the floor .. through friction, it just .. moves along until you stop applying the force.	Subject seems to hold the target misconceptions for options A, B & D but not for E. His answer would have been misleading to the original author.
3	Q:	Okay, and then let's look at number three, er it's referring to the same box, and you chose A, which says the box will stop suddenly.	
3	A:	Okay, `a large box is .. floor - will stop suddenly' well that's actually a // for me because it depends what surface it really is. I suppose if you're pushing on it - sometimes it'll slide a bit along - when you start pushing it but I dunno how far ..	
3	Q:	When you say sometimes um ..	
3	A:	I think I was a bit .. I was being a bit naive here, thinking it only just stopped, so I should have actually thought about it still sliding on a bit - bit to the point where the friction takes it - stops it.	Reconsiders answer, realizing that the box should slide on for a bit.
3	Q:	Um, if you were then to take a second look at the question, er ..	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
3	A:	Well I'd probably say .. er B .. ja 'cause it .. will just .. gradually slow down .. er stop .. and .. well it can't like merely start slowing to a stop - ja C as well; `continue with constant velocity' no, because friction obviously is acting on it - that idea you get as though it's merely carrying on and on like space, but .. that's not the thing.	Inarticulate.
3	Q:	What er .. under what circumstances could um .. D possibly be true?	
3	A:	Continue at constant velocity, // no friction at all, .. just carrying on - like I suppose in space or something, .. the idea is it that just carries on and on and on, the same .. projectile speed .. or velocity.	Good answer.
3	Q:	Alright, and um as you sit here now, what would you choose as your answer?	
3	A:	I'll take .. er B, I think .. um .. er A is still valid, I suppose ja B as well, and .. C. // A, B and C .. one - one // d'you have to choose between all those?	Mystifying!
3	Q:	Well alright, choose one of the ones that you have shown a liking to as the best.	
3	A:	I'd say C.	Correct answer.
3	Q:	Okay, now if you were to go back to A and someone were to say to you: `under what circumstances would A perhaps be true?'	
3	A:	Er um .. if it was, okay, a very rough frictional .. force like er .. I suppose .. just for example // in my head, I suppose I see myself on a very rough carpet maybe, pushing along, you know, if it was very .. rough ..	Good answer. Also a very large frictional force would make option A an accurate description of everyday experience.

	MAIN INTERVIEW NINE		
Q#	STATEMENT		COMMENTS
3	Q:	What sort of box?	
3	A:	Ja, what sort of a box? Kind of a, you know .. know just a .. a six sided box, perhaps just a ..	
3	Q:	Size, mass?	
3	A:	Pretty big, bulky, .. // along and stuttering along, da da da da; and he's pushing it .. being forced along more than pushed along.	No mention of the speed of the box given in the question stem; 4 m/s is a considerable speed. Target misconception cannot be supported by the interview evidence.
9	Q:	Right then, I'd like to jump ahead a bit to number nine, .. where you've chosen A as your favourite.	
9	A:	//// I do see it valid, let's see the other ones ... Well for B, it sounds as though it's just staying still. `it equals that of gravity', makes it .. sounds as though it's not moving at all, it's just .. stationary. Okay, C, ... no it can't be C, .. `is less than the downward'.. then it would be .. going downwards. It makes it sound as though gravity is .. stronger than .. going up ..	Target misconception for this option seems to be held.
9	Q:	So what would it then do?	
9	A:	Go down!	
9	Q:	Alright ..	
9	A:	And D, // `it goes up because the cable is being shortened' .. what .. I can't see what .. `because of being shortened .. not because of the force being exerted on the elevator by the cable' .. um well I thought well that was like .. what .. the cable being shortened, that's because of its force .. but it's going up .. //	Garbled & inconclusive.

	MAIN INTERVIEW NINE	
Q#	**STATEMENT**	**COMMENTS**
9	Q: What do you think they meant by that phrase: `the cable being shortened'?	
9	A: Well obviously // if it's being shortened, it's going up .. surely, but .. when you like think of // in terms of .. force, um just because .. I dunno .. it leaves you kind of .. left thinking of the case going up, but it's obviously not saying much about it.	Seems confused by option D.
9	Q: Mm - hmm, .. any comment on E?	
9	A: E, `the upward force on the elevator ..' well it makes them sound as though it's only - the effects of only air pressure and gravity which are causing it to go up, which obviously air pressure and gravity a- .. are the resistance and the person's weight to .. actually ascend; so um ..	Confused; maybe reading error.
9	Q: Tell me more about the air pressure they mention there.	
9	A: Air pressure? Well I suppose air pressure tends to play a part .. as in resistance going up.	
9	Q: How does it work, though?	
9	A: Air pressure?	
9	Q: Mmm.	
9	A: I suppose .. a very menial amount as the higher it gets up, the less um air there is .. so therefore .. er it // like such a small amount of difference but I suppose it is to be taken into consideration .. er it does .. give a bit of resistance .. going up .. of course gravity does	Confused.
9	Q: Okay, and what direction does air pressure act in, generally?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
9	A:	Air pressure? I think ja, like gravity .. kind of er .. the resistance might go up .. like an elevator; .. you never really think of it as an .. as an - that it really affects you much, but .. I suppose it does .. um .. just .. I dunno, air pressure's just .. very slight on the - over .. // .. I don't really relate to it as resistance much - sorry.	The difficulty in a) expressing himself and b) in understanding the interview questions rate as serious linguistic confusion.
9	Q:	Okay, um .. so what would be your final choice on that one?	
9	A:	Er .. are you only allowed to choose one?	
9	Q:	Well, you can choose as many as you like .. how do you feel about it now?	
9	A:	Um, .. think about D, does kind of .. make sense, it's being shorter so it's obviously going up, .. um I dunno if they really make .. an exact .. um well choice of reason there, but, lemme think .. // um .. think I'd just take .. the upward force .. /// C, they .. need um .. I'm not too sure, really .. takes .. a C maybe, /// no, not //.. um, A, D, E, .. I dunno.	Final analysis: Target misconception along with considerable linguistic confusion.
10	Q:	Okay ..right let's take a look at number ten then.	
10	A:	Okay.	
10	Q:	Now in number ten, you first chose A, you cancelled that and then chose E.	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
10	A:	Maybe there was something .. oh ja 'cause sometimes, here, you know I scribbled this out ... and when you go the next question it's sometimes like .. I dunno, the gaps are so far - the distances are so far away, sometimes you have a - like A, you've answered the previous question and you come to the next one, you don't really see A there, so you kind of see `oh, I've marked it just over there', and you go back to that line, I did it again, see? .. So that wasn't like ` Oh I made a mistake, let's cross it out' so that was - that was ..	No significance to be attached to choice of option A.
10	Q:	So that was - that was not - not actually an intentional answer?	
10	A:	No, it wasn't. //	
10	Q:	Alright, so then your - your first choice would then have been E?	
10	A:	Okay, this one was ten. ///// .. `While the object is moving upwards, the direction of the forces on it ... um .. the object is thrown straight up in the air' .. er there's no force acting upon it, so it's that .. a force is being constantly applied, so it's just like a - like a bullet being shot up, - instant force .. projects it and then the act of gravity slowly brings it down and down and down, slower - slower, eventually it reaches its pinnacle, .. comes back down again.	False positive: subject's explanation clearly shows that he does not hold the target misconception. He may for some reason believe that gravity is not a force. The fault may lie more with the subject's personal meaning for `force' that with his mental models.
10	Q:	Alright, so we'll stick with E.	
10	A:	Ja .. that - that wasn't intentional //// .	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
11	Q:	Okay ... Um .. then .. any comment on number eleven where you've given A and C?	
11	A:	`In the real world situation, which of the following statements is are correct?'..	
11	Q:	First of all, what did you think they meant by `the real world situation'?	
11	A:	I dunno, sometimes always .. the real world is more like .. the way you see it, not really the - the real .. um truth about it, the way you just .. think about things .. how you believe it, .. rather than the scientific way of ..	Subject appears confused about the meaning of `real world situation'.
11	Q:	Okay?	
11	A:	So .. `when the object is moving upwards, friction acts down .. on it' friction .. er .. ja, in the real world, you wouldn't really think about that, .. I didn't really think about A .. er what did I choose?	
11	Q:	A.	
11	A:	`When the object is moving downwards, friction acts downwards .. er acts upwards on it' .. ja .. friction acts upwards on it ... no I wouldn't - wouldn't regard B in the real world - you wouldn't think about it .. as something trying to keep it up still .. friction .. `The time taken by the object to go up would be longer' .. ja; C, I'd take. .. `The maximum height reached by the object would be smaller' .. er I dunno .. `The object would take longer to come back ... ' um let's take C ...	Other than the subject's apparent mystification it is difficult to conclude anything from his answers.
5	Q:	Okay, can we .. just go back to number five .. and your answer there is C.	
5	A:	/// .. just before it reached Y .. so you - // saying just before it reached Y?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
5	Q:	Hmm.	
5	A:	Because I - when I get the idea // the one says `just before Y' .. it sounds as though .. ja I think it could be because as a spring is coming to its final end, it still hasn't got as much .. as er force er so much impetus as it does .. at the beginning there because it .. springs always shoot out .. like the strongest point when you try and compress one .. the strongest point is certainly when it's er smallest, so when it comes to .. just to the - the end it - it's been released, not quite as .. strong I'd say, but // the thing is er it still builds up though .. so I think A would be .. a possibility.	
5	Q:	Hmm?	
5	A:	So `acceleration of the ball was decreasing on its way from point Y to point Z' .. ja .. it does decrease because obviously gravity acts on it, .. right and then `acceleration was zero at point Z' .. well .. zero at point Z .. when I say zero: .. not constant .. // it's just .. um .. well ..'suppose it is zero, 'cause it has stopped; there is a point where it has stopped. `All the above responses are correct', ja. `The acceleration of the ball was the same for all points on its trajectory .. from points Y to Z'. Actually what did I choose, C?	
5	Q:	Mmm.	
5	A:	Actually I'll take D, now.	Target misconception?
5	Q:	Okay. Could you describe the ball's motion starting at point X and say ending at point Z?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
5	A:	Right er it starts off from point X, and the spring's loaded down so it's about - it's got like potential energy to shoot up I suppose; the ball gets flung up - shot up .. and at point Y .. well just before point Y, it's - it's like .. full acceleration // and it goes up, up, up, sl- um acceleration decreasing - ja velocity decreasing, till it reaches point Z where it comes to a stop for a split second and comes all the way back down again; speeding - er er speeding up as it goes down .. till it reaches .. its lowest point, X, again.	NB: swops from `acceleration' to `velocity'; then no further incorrect use of `acceleration'. This seems to indicate verbal confusion rather than conceptual confusion. Could thus be false positive but not enough evidence to be conclusive.
5	Q:	Okay ... And er .. your final choice then?	
5	A:	D.	
7	Q:	Okay .. then .. number seven .. and in number seven, just confirm here, it looks as if you first chose E and then cancelled and changed to D.	
7	A:	Ja, that's what I did. //// Ja well, with this question .. the first .. set of blocks are obviously speeding up, .. and the second one's at constant; and it starts off with a constant one .. or in the beginning it starts off with a constant one ..	Correct interpretation of block spacing.
7	Q:	No hang on, what value is constant, though?	
7	A:	What value?	
7	Q:	Ja.	
7	A:	Well - one, two 'n three, .. four.	
7	Q:	No but is it speed, acceleration, .. what?	
7	A:	Oh .. velocity.	Correct.

	MAIN INTERVIEW NINE	
Q#	STATEMENT	COMMENTS
7	Q: Right .. um ... yes, how do you know that .. the lower of the two blocks is .. at a constant velocity?	
7	A: Er because the spaces are .. look, I didn't take a measurer, but they're // because they're the same distance apart.	Correct interpretation of graphic data.
7	Q: Okay, and the top .. set?	
7	A: The top one starts off slow and builds up. So // that's a constant acceleration, maybe? It's going up .. you know?	
7	Q: Alright then look .. look at the other options, right?	
7	A: 'Do the blocks ever have the same speed?' Um there's one thing that got me here, and that's why didn't they start in the same spot? Because then it would've been easier to work it out but .. but the - the real lines, the distance is er .. don't tell you that much. The real li- /// as if they really ...	
7	Q: ///// I think you can .. you can regard that out as a um .. a distance measurement.	
7	A: So um this - the first one starts off just at the head, and s- I'm sure there is one stage where the speeds are at the same, but not for long because the first one's obviously building up all the time ..	
7	Q: Okay, what stage is that?	
7	A: .. and I think well the distance apart would .. say in which way it was .. we'd have our measure but judging, it would be three and four, two and three.. ja I'd say .. that one and that one. // two ////	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
7	Q:	Alright .. so having gone through that thought process, what's .. what would you say is the answer now?	
7	A:	Say, .. B. Er I was thinking, that one, that one; um .. sometime between three and four .. three, four .. ja, I'd take E.	E is the correct answer.
7	Q:	Okay, you originally chose E and then you cancelled and changed to D.	
7	A:	Ja, what's D say? /// no, no certainly not, I'll take .. E, I'm right, E again.	Very definite about liking E & rejecting D.
7	Q:	But .. can you .. possibly remember why you made that change originally?	
7	A:	No, I was being stupid. I dunno, but .. when I look at it now it's incorrect, really 'cause .. /// they'd both be the same at that speed.	No misconception, choice of D must rate as a false positive; cause unknown.
8	Q:	And then .. have a .. look at number eight?	
8	A:	Eight? `The positions of two blocks ..' Block A looks as though .. is it .. is it looking as though it's constant? I can't tell really .. ja .. I dunno .. `acceleration of a equal to the acceleration of b which is greater than nought' ... In B it sounds as though they were at the same acceleration - speed that is .. but .. the gaps are different sizes.	Using `acceleration' in place of `speed' by mistake; (corrects himself).
8	Q:	What do the gaps - the sizes of the gaps tell you?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
8	A:	That a is quicker th- .. the position occupied by .. there's a flash thing that's going ta ta .. // so block b's going .. far quicker .. ja .. block b is going quicker than .. block a; and .. with option B, you kind of get the impression that .. the acceleration's th- .. that acceleration's the same .. and it isn't .. obviously and .. acceleration's greater than nought .. ja well, ja but I don't think it's that one; `the acceleration of b's greater than the acceleration of a', ja B, I mean C, would be one; `acceleration of b equal to the acceleration of a, is equal to nought' .. er C, I think .. what I said before.	Correct interpretation of graphic data. Lapses; returns to using acceleration instead of speed.
8	Q:	Okay, um .. just briefy, how would you define acceleration?	
8	A:	Acceleration is a constant building up - it's like velocity's always - if a constant velocity is always the same speed, a constant acceleration is .. like velocity is still going up, up, up; like the speedometer on a car, a constant acceleration, two metres a second, is going up all the time, two metres a second, two, four, six eight, keep on building up all the time.	Garbled definition but demonstrates that his meaning for accelleration is basically correct.
8	Q:	Alright, so your final choice then was, what did you say again?	
8	A:	Acceleration of b was greater than acceleration of a; C, `not enough information to .. ' I - I'd stick with C, I reckon.	Possibly target misconception but not conclusive.
12	Q:	Okay, um ..then let's look at number twelve .. and er what // this for me .. was what happened with er // you've crossed out B ...	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
12	A:	I think I made a- .. er maybe I .. didn't see .. maybe I think what I probably did was I went to the next question, saw it was B, so I like chose B, but I put it on that line because I didn't see E, 'ca[illegible]e the lines are equal distances apart /// the reason they all got //	
12	Q:	You tried to answer thirteen before you answered twelve or // you just mixed the lines up?	
12	A:	No I answered twelve, but I mixed the lines up.	No significance.
12	Q:	Oh dear. Right, then your answer to twelve is E?	
12	A:	E.	Correct answer.
12	Q:	Okay.	
12	A:	`At which of the points mentioned in the diagram if the force on the cannon-ball .. the greatest?' // I said- .. oh what did I say? ... I'd say A now.	Option A consistent with misconception.
12	Q:	Mmm? So what force are talking about in ///?	
12	A:	Well, .. acceler- the speed, as in .. ja, forces- because the speed's greatest at that point .. ja, I said `the force is the same at all four points' .. I - I dunno why I said that, I don't think - I say A now 'cause it's just that .. um it's been shot out, obviously .. at, you know, at quite a strength, and if it gets shot out, at point W, out of all the .. options, I'd say it would be strongest, because it's going fastest.	Rejecting correct option in favour of incorrect one. Could perhaps be entertaining an impetus-like notion.
12	Q:	Okay, and the other - what about the other three points, what is it doing at the other three points?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
12	A:	Well, at X it's slowing down, 'cau- otherwise it was the same, carrying on, like in space, er all the way ..	
12	Q:	What makes it slow down?	
12	A:	Well, obviously gravity .. plays a part, and air pressure, .. there's weight, ja, it reaches its point X where it starts .. slowing down although, I suppose in a way, gravity also makes it - the force .. increase, you know in a way, but not as strong as ec- as W; because you know it's going tot- ..faster and faster down together so .. I would - I would question ///// .	Could be target misconception but this would not have been evident independent of the interview as the subject originally chose the correct option.
13	Q:	Okay, and then number thirteen?	
13	A:	`At which of the point mentioned in the diagram is the effect of gravity the greatest?'	
13	Q:	And there you chose B.	
13	A:	The effect of gravity? Well, you might interpret this question as being the effect as er, .. is the effect the strongest, is it - at which point is it the strongest, gravity, or like is it - is it you can probably say that ..	Subject perceives that the question might be interpreted in various ways.
13	Q:	Er what - what did you interpret that to mean?	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
13	A:	Er ... effect of gravity? .. the greatest? .. Er I'd take it as .. er Z .. because .. um that's when, I suppose .. I dunno, // that's kind of a strange way of asking .. I dunno it's just kind of strange to say `which point is the effect of gravity the greatest' .. I see now .. I think I may have chosen X because .. it was at that point where um as it reached a point when um as it reached a point where the force wasn't er beating as you could say, .. um gravity, it was at that point that it started - the gravity er started .. taking over .. more .. and .. er point Z .. is kind of like .. er no actually I'll take X, still .. where I understand that as being .. the effect, like .. ja just .. ja, I reckon it's the way the ques- the answer'll be B, I'd still say.	Takes point X as the point where gravity finally overcomes the impetus and succeeds in turning the projectile toward the ground. He interprets this as the meaning of the `greatest effect of gravity'. As impetus is not regarded by the original author as the target misconception, this must rate therefore as an untargeted misconception. Also false positive: no evidence in the subject's comments of the target misconception.
13	Q:	Okay, and if you were to put into words um your meaning .. of the er term `the effect of gravity'?	
13	A:	The effect of gravity, when does gravity actually overcome the force applied; wh- wh- when the body, kind of thing, when does it actually, well kind of `beat' the applied force.	Confirmation of analysis above.
14	Q:	Right let's then cross to number fourteen, on the following page; .. and again your answer there is B.	

	MAIN INTERVIEW NINE	
Q#	**STATEMENT**	**COMMENTS**
14	A: /// In this question, um they weigh the same so obviously they were at different heights so because of the weights: they're different, so I suppose you could say that one is on Mount Everest, that one's at sea level, um .. as I say, I guess it is that you weigh more at sea level. Ja that one is at sea level, I think and .. `who experiences the greatest gravitational force' .. oh oh in this question .. the closer you get to the earth the stronger the - the pull, so um the one who weighs I'd say .. the most would um be attracted - would experience the greatest gravitational pull - so I'd take C, and that one is ..	Shows good understanding of relation between altitude and force of gravity and must have chosen as he did by mistake.
	[tape ends; turned over]	
	Well for question fourteen, I'll take C, as I see it now.	Subject now reconsiders and changes his choice of option to the correct answer.
		Original choice amounts to false positive.
14	Q: Okay, any idea why you chose B at the time?	
14	A: Um .. I dunno why, maybe I wasn't quite thinking straight.	No indetifiable reason for his original mistake.
14	Q: Okay, and then comment on number fifteen, where you also chose B?	
14	A: `Who is closer to the earth's centre?' .. C .. ja C, the two are related.	Reconsiders choice, now correct; false positive.
14	Q: Ja and er, again any idea why you chose B?	
14	A: Hmm .. no, sorry.	Unknown origin.

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
16	Q:	Alright .. then let's have a look at number sixteen, where your answer is also B.	
16	A:	`What is the most likely reading on the spring balance if the apparatus is taken up to the top of a building in Durban ..'// um I'd take .. take D. I think I got this the wrong way round now because throughout my questions I've been saying that .. the less you weigh the closer to the earth you are - the closer to the centre. I dunno, like this one - this one, I chose B; each time, I come up with the opposite.	False positive, subject reconsiders and now chooses an option which is arguably correct. He states that he has been reasoning all his gravitation questions `inversely'- this would be a misconception had he not realised that it was wrong.
16	Q:	Mmm, any idea why you did it that way round?	
16	A:	I dunno, maybe I just got mixed up, but .. it was a long day, and /// not sure - obviously a bit delirious.	
16	Q:	Okay, for sixteen now you say you would choose D?	
16	A:	Yes.	
16	Q:	Okay, .. could you explain why?	
16	A:	Well .. if you're going further away from the earth's centre, .. slightly, even if it's fifty metres, the - the less attraction that the earth or less strength or gravitational force that the earth has on you, the further away you leave it.	Correct except for the scales involved.
16	Q:	Okay, .. and er how much is slightly?	
16	A:	Barely .. point something .. nought point nought nought I'd say .. of the weight - fifty metres is .. is nothing really, compared to .. ja fifty is really .. nothing at all.	Realises that the difference is very small, but perhaps not <u>how</u> small.

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
16	Q:	Okay.	
16	A:	Ja I suppose it would be ninety point nine nine.	
17	Q:	Okay, then number seventeen ..	
17	A:	//// D, not B .. ja, I think I was working the other way round, ja I'd say D now .. just that it's kind of the same as the previous question that the further away you get, the less strength that the .. object has ..	`Inverted' reasoning used again, thus another false positive.
17	Q:	Alright, um if you're going to now choose D, any comment on how much less .. than question sixteen's answer?	
17	A:	Well, what I previously said was twenty .. newtons, and I would say it would go down to about eighteen .. what's that, less than six- it says less than sixteen? Maybe it is I - I suppose about actually C, I never really .. considered like how really high Mount Everest is to sea level or - ja as we compare it to sea level - I suppose about sixteen newtons, I wouldn't make it as much as like ten .. it seems that's a hell of a lot of weight .. like wow.	Reveals lack of knowledge of the scales involved and also misreads the wording of the option as: `less than 16 (newtons)' rather than `less than in (question) 16'. This clearly does <u>not</u> aid him in reasoning well and amounts to evidence of linguistic confusion.
18	Q:	Alright and .. let's just consider some individual questions, in number eighteen .. um your ..	
18	A:	I think I did it again.	Repeats orientation error.
18	Q:	In that case your answer for number eighteen was E.	

	MAIN INTERVIEW NINE		
Q#		STATEMENT	COMMENTS
18	A:	E, eighteen .. 'in the arrangement shown, block B slides on a smooth table. The force F acting on B is exerted by' .. the pulley, the table, the string, the earth. I chose what?	
18	Q:	E.	
18	A:	Pulley .. I'd say ..probably the earth because .. gravitation .. of a .. pulley .. I suppose .. wait; a force ac- acting on it is exerted by .. the earth .. so .. maybe it .. ja, B I'd say.	Reconsiders, rejects original choice and chooses B. No true false positive as original author does not specify what choice of this oftion signifies.
18	Q:	Okay, and what about some of the other options?	
18	A:	The table, well .. um no you can't have - the table's just the er .. um the table .. the string, no, you can't just say that .. the pulley, no, .. I'd take the earth, block A, ja but if the- block A's just going to be influenced by the earth.	Justifies his new choice with good reasoning.
18	Q:	What role in the situation does the string play?	
18	A:	Well, the string's just the - the attachment from B to A, which .. well .. er A just .. influences B to bring it down, that's all: it's just like a connection.	Shows complete awareness of the string's role in the situation.
19	Q:	Okay, then number nineteen .. your choice was A.	
19	A:	'Which one of the following may not be a true statement about a body in uniform motion?' ... um D and .. A, are the two.	A case can be made for each of these options as a correct answer.
19	Q:	Okay, and er ..	

	MAIN INTERVIEW NINE		
Q#	**STATEMENT**		**COMMENTS**
19	A:	I left out D, I said - I just said A. Sometimes you - you get - no .. `which one of the foll- .. may not be true' which is kind of .. which .. only one, so I suppose it's .. A .. but D's also valid. Actually D sounds even better now .. the more I think about it now .. I think .. D appeals to me more.	
19	Q:	Alright, what about some of the others?	
19	A:	Well, `velocity may be constant' .. may not be true about // .. ja, th- this is .. // is true but B is true; and its acceleration may be constant', no .//. and E, `its velocity may be varying' .. no you can't have E either, so A, D and E are the three .. which apply to the question.	Failure to recognize E as the correct answer is the best evidence available that the subject holds the target `misconception'
19	Q:	Okay, and what's your .. what would be your single choice?	
19	A:	// .. I think D .. ja D.	
20	Q:	And number er twenty - in twenty, your choice was C.	
20	A:	`Which one of the following assertions concerning an astronaut standing on the moon is true?' .. A is false, because it does hold some .. just because it hasn't got an atmosphere .. it does have some .. it may be very weak force, but it does have some gravitation pulling us to it. `The astronout experiences no force .. ' B isn't true .. ` The astronaut only experiences a downward force as a result of the moon's gravitational attraction.'	
20	Q:	Sorry, just repeat that one please.	

	MAIN INTERVIEW NINE	
Q#	**STATEMENT**	**COMMENTS**
20	A: // C is .. /// .. E, ja, as well, but again it says `which one of the following' `The astronaut only experiences an upward force exerted by the moon's surface' .. ja but .. I reckon D, C.	
20	Q: Why did you prefer C?	
20	A: // I'd take D, er it also brings into the er // it's also got the moon's er surface .. it brings in more about it .. so I'd take D now , er C ..	Reconsiders and chooses correct answer: no misconception; false positive
20	Q: Any idea why you chose C at that particular time?	
20	A: Maybe /// come back to it .. I dunno .. I just took a .. can't remember.	Reason unknown.
20	Q: Right then, thanks very much.	
	END OF INTERVIEW	

APPENDIX 3c: INTERVIEW TRANSCRIPT

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
1	Q:	// will you kick us off please Mark, with er .. your reasoning behind your answer to number one, to which you gave the answer A?	
1	A:	Er .. er the reason why I gave it um, um that B reaches the floor first, if the object is hit or .. is that if this object can travel .. they didn't really say which um - how much force is behind .. object A, so if object A, it can go for .. like er .. if this is er like er ten metres above the ground, it's going forwards like er .. er for instance like a tank .. shooting, it could go for .. say sixty kays; therefore this would be flying at - going sixty kays and it wouldn't hit the ground yet .. but this being about ten metres above the ground, you'd say .. would have enough time to fall down before .. the other object hit the ground.	No evident distinction between vertical and horizontal components. This amounts to the target misconception fot this item. Unrealistic idea of scales involved.
1	Q:	Okay, .. now .. what about the other options, for example um .. B?	
1	A:	`A reaches the floor first because it is given a finite initial velocity.' Um .. ja .. `first because it .. ' I mean no because it's given a limited (right?), a limited initial velocity // so you're saying that .. A would reach the floor before because .. // no I wouldn't say, ja .. because I say they didn't give us enough information to say that, you know, .. because this can carry on going .. 'cause they said um .. no they didn't say /// the air was taken into account ..	Still no indication of any discrimination between the two components.
1	Q:	Okay, um .. C?	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
1	A:	Um .. no, I wouldn't say it travels shorter, that A travels shorter, 'cause they didn't say what distance - // they didn't say what the force behind it was, 'cause B will just roll off A, while A will carry on, .. going, so they say that A reaches the floor first because it reach - it travels through a shorter distance to .. to the floor; no, I don't think so.	Still no discrimination between vertical and horizontal components.
1	Q:	And finally E?	
1	A:	Er .. No 'cause B wouldn't have a velocity, .. I don't think, it would have a bit of velocity but wouldn't have the same velocity as er .. A had when it was projected off.	As above.
5	Q:	Alright, okay, let's leave number one and then we'll skip across to number five; .. and um, .. I wasn't too sure how to interpret that, .. from what did you ..	
5	A:	Um, .. I think I gave .. C, .. because um, I said that acceleration was zero, because as it came higher up, when it got to that point, // Z, // it - it like stalled and there was no acceleration at that instant, // but then gravitational pull pulled it back down after Z and then it would accelerate .. up again.	Indicative of possible misconception: either i) velocity & acceleration undiscriminated or ii) belief that gravity stops acting briefly at top of flight.
5	Q:	So you're saying there that C was your final answer?	
5	A:	Ja.	
5	Q:	And then what put you off D?	
5	A:	/// Hmm, .. they said that um .. was - was the air resis um .. oh, seeing that the air resistance was negligible, but there's still gravitational .. pull on this thing, .. um ..	
5	Q:	D is the one saying `all of the above responses are correct'.	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
5	A:	Not correct, um .. /// ... um, I think I - I think I find this one a bit strange but .. but the acceleration would be .. I think it would be just the velocity that goes .. that becomes ..	Possible verbal confusion between velocity and acceleration.
5	Q:	Which one are you referring to?	
5	A:	Er E, ja, .. I thought that maybe the acceleration would be constant .. all the way from point Y to .. Z.	Possible indication that the confusion mentioned above is not conceptual.
5	Q:	Uh hm, and .. A?	
5	A:	// I'm not sure about that .. about // in contact with the spring, because it would be projecting off but then .. maybe it would be .. maybe it would accelerate .. from Y to Z out, .. as it's realeased, you know? // the spring .. .	Too vague for comment.
5	Q:	Alright then, what about B?	
5	A:	Um, `acceleration was decreasing from point Y to Z', .. um, ja .. just trying to remember my science, // acceleration .. I think, I think it actually um .. the - the velocity would slow down .. but um I'm not sure if the acceleration would slow down - I think the acceleration would .. um ja because the acceleration would um be given the er the starting off acceleration, and that's carrying on but then it's slow down due to er the gravitational pull.	More possible confirmation that the confusion between acceleration and velocity is merely verbal rather than conceptual.
5	Q:	In which part of the diagram does it get its starting acceleration?	
5	A:	Er, I'd say from point X to Y.	
5	Q:	Okay, and then after that what happens to it?	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
5	A:	Erm, .. now that I go over it, I - I think maybe `all the above responses' might - might be correct; .. but I still think that the acceleration is zero at Z, so ..	Response contradicts some of the earlier responses thus a firm conclusion is not possible.
6	Q:	Okay, and then the next one on the list is number five.	
6	A:	Oh .. okay .. don't you mean you wanna do number six?	
6	Q:	Sorry, your - you're quite correct, the next one is number six; your answer there is D.	
6	A:	Um .. six .. okay `two people are //// ' .. okay they say `a large man and a boy' so we .. think the large man has more strength than - than the boy so if the man is pulling .. and the boy are pulling at the same - pulling on the same block and they're about the same you know, the angle .. is the same, we think, so and I said they'd be pulling at angle D, because er the man is pulling stronger, we think, so he would be .. going faster, I'd say pulling it - pulling faster, he's got more strength than the little boy, he would tend to angle round, 'cause he's pulling faster than the small boy, so he'd pull round and .. he would go faster, [the boy] would go slower and they'd tend to pull round towards D.	Subject has somehow interpreted this situation to be that the man and the boy pull in the same direction: he uses `angle' as a synonym for `direction'. This being the case, his answer is a reasonable prediction of the resultant behaviour of the crate. This could thus reasonably be regarded as a false positive of linguistic origin.
16	Q:	Okay .. and then um, .. after that number sixteen.	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
16	A:	I think it - I think it's that one .. // okay, they - they don't tell you that um .. so this would be actually weight so .. I dunno why I put A, because it should .. if it go - if you go higher, shouldn't that decrease? But at fifty metres, that's hardly anything, so I don't think it would actually, .. I think it'd actually stay at twenty .. newtons, because it's such a small distance, I don't think it actually .. is affected much.	No misconception being demonstrated here.
16	Q:	So as you sit there now what would your answer be?	
16	A:	Um, taken up to fifty metres, I'd say - I'd say it's um twenty newtons, I wouldn't say it would actually decrease at that .. you know that - only fifty metres is quite small.	No misconception.
16	Q:	Alright, any - any idea as you sit there why you chose A originally then?	
16	A:	I'm not sure, .. I think it might have just been a .. mistake maybe. I'm not saying that it's heavier at fifty metres than it was at twenty .. um no I don't agree with that.	Original incorrect choice inexplicable. False positive.
17	Q:	And then number seventeen, which goes with it?	
17	A:	Um .. if you take it to eight thousand, eight hundred metres ...	
17	Q:	Again your answer was A.	
17	A:	Well .. // .. strange, .. I think I might have been thinking of C .... because that's like implying that if I go up to mount everest, I weigh less than I do down here .. I'm not saying that ..	
17	Q:	Which is?	

	MAIN INTERVIEW SEVEN		
Q#	STATEMENT		COMMENTS
17	A:	I don't think that it's right.	
17	Q:	And what about Mount Everest then?	
17	A:	Um .. I don't think it actually goes down either.	No misocnception.
17	Q:	What does happen?	
17	A:	I think it stays .. the same.	No misconception; conclusion as for previous question.
17	Q:	Alright, and if you went up even higher, .. some really high altitude, along .. space shuttle sort of altitude?	
17	A:	Well then - then you start getting away from the earth's gravitational pull, b- but here you're still on earth, // you're not - you're still in contact with earth, I'd say and .. if you go into a space shuttle, you're going then outside the gravitational pull and then // slowly .. but not such a small distance, I would think.	Possible untargeted misconception regarding the inverse square law?
12	Q:	Okay, before we go to my next marked one I just want to have a quick look at number thirteen, .. um .. number thirteen is linked with number twelve, so let's just briefly look at twelve first ..	
12	A:	Okay, `at which of the points of the points mentioned in the diagram is the force on the cannon-ball the greatest?'	
12	Q:	Okay, you gave there D.	
12	A:	Um, .. the force, would it be the - the force coming .. actually out of the cannon, or would it be the gravitational force?	Sees two possible interpretations of the question text.
12	Q:	Well how did you interpret it?	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
13	A:	Um .. yes, because as it comes to that point, like if you throw a tennis ball up, it's going to come to a point where it will like .. stall; it'll .. there will be um .. the acceleration will be nil and the velocity will also, and then that's where gravity is the only force actually acting on that point - acting on that object so there it would pull - I think X would give the largest because that's where gravity is the .. most because there's no other force when it gets to here, maybe just a bit of .. forward force, but the main gravitational force would be pulling it down.	Answer seems consistent with the lack of knowledge of the inverse square law demonstrated by his discussion of question 17. It is also consistent with the notion that the force of gravity increases with altitude, which is the target misconception for the chosen option in this question.
13	Q:	Okay, and then number thirteen, what do you think they mean by the phrase `the effect of gravity'?	
13	A:	Um, the effect of gravity being that of the - the pulling force of gravity, .. the downward force of gravity, .. being towards the earth.	Target misconception.
18	Q:	Okay, then um .. my next listed one is number eighteen.	
18	A:	`In the arrangement shown, block B slides on a smooth table. The force acting on B is exerted by'	
18	Q:	Right, your answer was B.	
18	A:	Um .. I took it as saying if .. I put B?	
18	Q:	Ja.	
18	A:	So that would be the earth, the earth is pulling is pulling on object A by gravitational force, .. and that would inversely pull on .. the pulley, pulling F, pulling B, so I'd say the gravitational force of the earth is what's pulling B, because it's pulling A.	Interprets question as asking for the origin of the force, no evidence of non-Newtonian thinking.
18	Q:	Okay.	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
18	A:	The string is the linking force between B and A, and A being pulled down by gravity will pull - by the string will pull B along the surface // the pulley.	Answer consistent with interpretation above.
18	Q:	Right, any merit in any of the other answers they've got there?	
18	A:	Um .. it wouldn't be pulled by the string because the string is being pulled by A, which is being pulled by the earth; the table, .. its not being pulled by the table because the table can't exert the force because it seems to be level here .. um and the pulley is just the means of converting the force from side er .. horizontal to downwards over the .. pulley.	As above.
19	Q:	Okay, .. um number nineteen? ... And your answer's E.	
19	A:	'Which of the following may not be a true statement about a body in uniform motion?' I said that E would not be a - a true statement because it said that velocity may be varying .. while they say that .. the body is in uniform motion. I interpret uniform as being um .. constant motion but maybe the constant might be - might be changing. What they're saying here that it's still moving but er .. ja maybe that wasn't the .. correct one.	
19	Q:	Well try and put into words what your interpretation of the term 'uniform motion' is.	
19	A:	I thought that uniform motion might be .. er constant motion being at the same ..	
19	Q:	What's constant about the motion?	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
19	A:	Um .. `its velocity may be zero' .. um .. getting mixed up here, but er doesn't .. it can have an acceleration of zero but then it'll be - it'll still be going, .. but if it has a velocity of zero, then isn't it .. like, you know, stopped? Or is it er .. I think it's linked up with .. isn't velocity linked up with acceleration?	
19	Q:	In what way is velocity linked up with acceleration?	
19	A:	Um .. linked up with acceleration .. I'm not sure, because velocity is the - the what do you call it, I think it's a bit like force .. acting on it, you know .. and then the er .. acceleration .. acts on it.	
19	Q:	And .. what is acceleration, then?	
19	A:	Acceleration's the er .. increase in velocity .. over a certain period.	
19	Q:	Okay, .. alright, what about er option D?	
19	A:	`Its acceleration may be constant', but then .. acceleration would be increasing the speed, // so it would carry on increasing the speed if acceleration was constant, but it says `in uniform motion' 'cause I interpreted that as being uniform speed, // so therefore .. acceleration may be constant .. uniform motion .. because - because unform motion is - is speed, it's - it's going but `its acceleration may be constant' .. er .. 'cause I interpreted it as being er .. you know constant speed but then the acceleration may be constant, it would be increasing the speed, // so .. that's why - what I can't ...	Demonstrating good understanding of the meanings of velocity and acceleration inspite of earlier inarticulate comments.

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
19	Q:	Could you make a .. very brief case for A?	
19	A:	`It's velocity may be zero' um .. if its velocity was zero, I think then there would be no - no forward force, or backward force, whatever the force might be, so there - therefore it would .. and they're saying `in constant motion' so therefore I think it would - would stop.	
19	Q:	If D is not to be one of your choices there has to be some way in which that could be a true statement about a body in uniform motion, could you make a case for that?	
19	A:	Um .. oh you're saying that .. a true statement, then this is true, that D is - you're saying that D is a true statement?	Forgetting that the question is phrased in the negative?
19	Q:	If you don't select D, as a possible correct answer, then there must be some way in which D could be a true statement.	
19	A:	Um .. a true statement .. because we said `in uniform motion' therefore I thought the acceleration wouldn't be increasing .. because if acceleration is constant then it will increas in, you know, in speed, so .. it can also be .. de-acceleration as well ..	No evidence of recognition of the possibility that the `constant acceleration' could have a value of zero.
20	Q:	Alright then let's leave that one and before we just pick a few other selected ones, um have a brief look at number twenty, seeing it's right here, and your answer is D.	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
20	A:	Um A: `the astronaut experiences no force because there is no at - not an atmosphere', um, no because the moon does have a gravitational force - slight gravitation so that wouldn't be - he would experience some force .. um not only because there is not an atmosphere .. er ..	
20	Q:	What has the atmosphere got to do with it?	
20	A:	Well, the atmosphere exerts a downward force - a pressure force but I don't think the - the atmosphere would play much role in the - on the moon, .. I think it would be more gravitational force. Um, B: `the astronaut experiences no force because only bodies near the earth are attracted by gravitation', er no, because er all er um planets have a certain degree of gravitational pull, it not only exists on earth. Then C: `the astronaut only experiences a downward force as a result of the moon's gravitational attraction', er that could also be er true but there has to be a force .. that supports him as well, or he's go through; er and then E: `the astronaut only experiences an upward force exerted by the moon's surface' er no that - because there's gravitational force as well.	Untergeted misconception: air pressure acts downwards & thus assists gravity! No misconception in evidence. Confirmation of Newtonian reasoning. As above.
7	Q:	Okay, .. alright and er .. next on my list, is um number seven ...	
7	A:	Er, `the positions of two blocks at successive // numbered squares in the diagram /// the blocks are moving to the right.'	

	MAIN INTERVIEW SEVEN		
Q#	**STATEMENT**		**COMMENTS**
7	Q:	Okay, but why not B, C or D?	
7	A:	Two um .. I didn't choose that because of the fact um .. that it was - this is increasing, because this is - this is um increasing and it - I think that .. because on the graph, um, they're not exactly placed on the .. because I think you actually interpret back to the graph, to decide where it is and the spaces aren't exactly - they don't run in er .. synchronised with the graph, because like, if you take two spaces there, they're not just like one - they're not like one is on number .. there, two's on there, three's on there, four's on there, but it runs differently.	Inarticulate, but no evidence of misconception.
7	Q:	Okay and then I think we're running out of time, so the last one, I think, will be number eight, you chose D.	
7	A:	Um, the blocks are spaced .. equally, at - the intervals are the same, I'd say, from the graph in both - both block A and block B, so the acceleration of B equals the acceleration of A, equals nought, there's no acceleration; because the dist - they're spaced equally apart therefore the acceleration is zero because they're going at the same velocity, .. they're going at the same - like with a ticker tape, // therefore there's no acceleration.	Correct answer, correct interpretation of graphic information, good justification for answer.
	Q:	Okay, thanks very much and the st Davids bell has told us that interview must now come to an end, and er thanks very much for your help.	
		END OF INTERVIEW	

APPENDIX 3d: INTERVIEW TRANSCRIPT

	MAIN INTERVIEW FIVE	
Q#	**STATEMENT**	**COMMENTS**
1	Q: Right, first of all let's do question one, where your answer is A, could you tell me why you chose that?	
1	A: Why I chose A, .. um .. well because um if er the object A is pushed off the table, it has a further distance to travel than B, which is acting .. or has the force of gravity acting directly down and it therefore has a shorter distance to travel .. than object A, so should reach the ground first.	
1	Q: Okay, could you just er give us a bit more about what you mean by being acted on directly by gravity?	
1	A: Well the er .. it doesn't have er .. the only force that acts on it is gravity and it doesn't have anything .. once A has been pushed away it doesn't have anything er .. holding it up - any force holding it up, it's acted on by gravity.	
1	Q: Now .. what about A, and gravity's effect on A?	
1	A: Er but, um you see A er has er two forces acting on it, there's A and the force one's being er pushed off so it goes forward as as it goes down so it um travels a further distance than than B, so technically um B should reach the ground first.	Subject seems to believe that an object's horizontal velocity can affect its vertical behaviour; thus he seems to hold the target misconception.
1	Q: Okay, and what about some of the other options in the question, .. um just briefly why you reject them, in in order.	
1	A: Well, well um should I start with C, or B?	
1	Q: Anything.	

	MAIN INTERVIEW FIVE		
Q#	STATEMENT		COMMENTS
2	A:	This, er that's um also er quite logical, I mean if you have a force moving a box at constant speed therefore the force must er remain er constant as well; um but obviously it has to be er more than the frictional forces because otherwise frictional forces would stop it from moving, that's why I chose D.	Target misconception: motion only when applied force overcomes resistance.
2	Q:	Okay and then let's have a look at the .. question three across the page, where .. the answer you've .. chosen is A.	
3	A:	Because, I chose this because um there is er a frictional force acting against the the the force of the box being pushed so if you take that force away, the force applied to the box, if you take that away, then um the frictional force will stop the .. box from moving forward.	Target misconception held, i.e. that motion occurs when a force overcomes friction, or as stated by original author: motion implies acitve force.
3	Q:	Okay, now um what meaning would you attach to the word `suddenly' which they have .. used in A?	
3	A:	Okay, immediate - an immediate stop.	
3	Q:	Okay er what sort of um box did you have in your mind when you answered this.	
3	A:	Er well a - a cardboard box // filled with something, I dunno, .. so - a heavy box.	
3	Q:	Okay and being pushed against what sort of surface, .. they simply say `the floor' so?	
3	A:	Erm well .. er I didn't really think about this; I suppose a .. er not - not a smooth surface, er nothing in particular but not sort of .. not a polished surface if you //.	Seems to be envisaging a large force of friction.
3	Q:	Okay, and um .. about question - what about option C in the same question?	

	MAIN INTERVIEW FIVE		
Q#	**STATEMENT**		**COMMENTS**
5	A:	Um, okay um, D um .. I chose D because um .. because of - because you can see the photograph, um the acceleration decreases as the .. as the balls er get closer together, because of the time er difference and er so that er so obviously between points X and Y the acceleration is the the fastest because there's no um .. um .. you don't see the ball between point X and Y and also because that's where the initial velocity comes from and since it's going up it will start slowing down .. straight away because of friction - frictional forces; and er .. obviously it decreases point Y // 'cause you can see there's er as you can see the the balls get close - closer to each other as they get closer from point Y to // and er obviously when a ball .. goes up it has a um .. at point Z, it - that's when it stops and came down again, so obviously there the acceleration is zero, 'cause that's when it stops.	Consistently uses 'acceleration' where he should use 'velocity'. This certainlly amounts to lack of discrimination between velocity and acceleration but what is not clear is whether it is on a verbal or on a conceptual level. Subject presents no clear evidence either way; he could be simply lapsing into careless word usage and using the one term where he should be using the other or he could actually have merged the two concepts. His next few responses seem to favour the former possibility.
5	Q:	Okay, and .. alright, now what about .. what about its velocity - you've spoken so far about its acceleration?	
5	A:	Its velocity? Um .. alright obviously its velocity is highest at um .. between point well point wh - point Y; and er decreases as it goes up and increases as it come backs - comes back back down.	Correct description of the changes in velocity during the fall.
5	Q:	M-hm, and um .. how does velocity and - how do in this particular question how do the velocity and the acceleration .. um .. relate to each other.	

	MAIN INTERVIEW FIVE		
Q#	**STATEMENT**		**COMMENTS**
5	A:	It's um okay .. it's um the increase of velocity um .. the um .. it's just the rate at which velocity increases .. over a certain period of .. time.	Definition vague but essentially correct.
5	Q:	Okay, and velocity?	
5	A:	Er velocity is the um .. it's .. well it's the speed of er something in a certain direction.	
5	Q:	Alright well that would mean what .. you would then need to tell me what speed is.	
5	A:	Okay it's er the rate at which um something travels; the er er amount of time .. /// okay er speed, .. it's the rate at which something travels er in a certain amount of time; um er the - how much distance it can cover in a certain amount of time.	Definitions vague but essentially correct.
7	Q:	Okay and let's have a look, if you'll just turn your sheet over and have a look at seven and eight, where in seven you've given the answer E .. and in eight, you've given the answer D; let's first do seven.	
7	A:	Alright um, because um .. if you um .. I answered E because um if you measure the distance between um block three and block four in both cases they are roughly the same distance apart, so um logically they um have the same speed in that time because they travel the same distance in that certain time.	No misconception; correct answer, well justified.
8	Q:	Okay, and then your reasoning behind your answer to eight?	

	MAIN INTERVIEW FIVE		
Q#	STATEMENT		COMMENTS
9	A:	Question nine?	
9	Q:	Ja.	
9	A:	Um obviously the amount of upward force on the elevator by the cable must be equal to the downward force of gravity otherwise the elevator would fall um because the cable wouldn't be able to hold it up, .. so that's um basically why I answered ...	
9	Q:	Okay, what would happen if A was true?	
9	A:	Um this .. it should be the same er if the if .. okay the cable - the elevator would rise.	
9	Q:	Hm? How er tell me more about how it would rise.	
9	A:	It um .. er um .. the cable would lift the elevator .. I dunno um .. if that's .. actually I don't - I don't think it would rise because um .. the cable wouldn't be able - wouldn't be able to lift the .. elevator, it - it would just be able to hold the elevator with more weight, if it had er .. if you know what I - I mean ..	
9	Q:	Okay, what would happen if C was true?	
9	A:	Well then the er .. the cable wouldn't be able to hold the elevator and the elevator would .. fall.	
9	Q:	Okay, and er why did you like D?	
9	A:	Well um .. that's logical as well because the cable .. the the force of the cable can't actually lift the elevator but the shortening of the cable will lift the elevator but the force of the cable can't.	

	MAIN INTERVIEW FIVE		
Q#	STATEMENT		COMMENTS
9	Q:	Right and then what about E, just to finish this one off?	
9	A:	Well, .. the combined effects of air pressure and the force of gravity would make the elevator .. the force of the elevator .. um greater than the cable - the downward force of the elevator greater than the upward force of of the cable which sort of um .. is contrary to what the question says - it says the upward force on the elevator by the cable would be greater than the downward force but with the gravity and air pressure it would make the downward force greater than the upward force, alright?	Seems to be entertaining notions of air pressure acting downwards or, in the original author's words 'air pressure-assisted gravity'. As the subject did not choose this option, this would rate as an untargeted misconception.
12	Q:	Okay then, I'd next like to look at question twelve and er .. question twelve's interesting because you first chose D and then you cancelled that and changed to A.	
12	A:	Alright um .. I first chose D because I thought um .. with gravity and er the force erm would be er the most but then I thought A would be because er A's when the cannonball has just left the cannon and the force acting on it is still pushing .. A up, therefore er I thought that would be the most - the force would be the most there because it's still got the force of the cannon behind it, if you know what I mean ..	Clear evidence of an impetus - like notion, i.e. target misconception.
12	Q:	Um .. in the two options what force are we talking about?	

	MAIN INTERVIEW FIVE		
Q#	**STATEMENT**		**COMMENTS**
12	A:	Well in X um the er force of the cannon um starts to lose its effect as it - because it starts going down at the - that's where it starts going down and also Y, it also has lost a lot of the initial .. force and it's mainly gravitational force acting upon it, becaust it starts to go down.	Impetus confirmed.
13	Q:	Right, um .. and then in question thirteen which speaks of the same cannonball they .. um .. ask for .. the effect of gravity and your choice was D.	
?	A:	Er this is er because um .. the cannonball has has fallen from er point X and it's fallen that distance and it's acel er - accelerated because it's been falling that distance .. so um .. technically this is where gravity should act upon the most because it's it's pulling it .. down.	Possible untargeted misconception: 'impetus impairs the ability of gravity to act on a moving object'.
13	Q:	Why would gravity act on it most at Z?	
13	A:	Because it's lost most of it's initial force from the .. cannon so it doesn't act against gravity, it's ..	As above.
16	Q:	Alright, then I'd like to take a look at questions sixteen and seventeen which also go together, first of all question sixteen, and you chose B.	
16	A:	Well actually for this question I - I didn't read the first comment but er I chose it because .. um what I thought was that er air pressure would be um .. um the air presssure - there would be more pressure than um wh - normally but er .. because I thought it would be er lower down but it - I didn't read this first part, that it was at sea level so .. I think that's why.	Subject states that he misread the question and that his reasoning and choice of answer were based on a decrease in altitude. This constitutes a false positive of linguistic origin.

	MAIN INTERVIEW FIVE	
Q#	STATEMENT	COMMENTS
16	Q: Umhm, what does a spring balance measure?	
16	A: Um isn't it um .. // um isn't it .. no, it's not .. it's mass or .. gravitational force or something?	
16	Q: Okay now how does .. how does air pressure connect with that?	
16	A: Well because um if you have um .. er air presssure, um higher air pressure then obviously there would be more of a downward force upon it but if you have er less air pressure there would be .. less - less of downward force on it so the measurements .. the measurements will be different.	Untargeted misconception confirmed: air pressure acts downwards and thus assists gravity.
17	Q: Okay and then .. question seventeen ..?	
17	A: Okay I said um this would be less because obviously um if you take it to the top of mount everest um there would be less air pressure .. because you're a lot higher, so um .. that's why I said it would be less than question sixteen.	Untargeted misconception; as above.
18	Q: Okay, .. alright then er .. question eighteen, just very briefly, erm, your choice for eighteen was A; could you tell us why?	
18	A: Mostly because um .. er because A is being acted upon be gravity and B is being pulled by A, over the pulley, so the force of A being pulled down will pull B - B along, // it's not the force of the table or the string, it's the force of A going down.	Interprets question as asking for orgin of force. Probably did not read the question carefully enough to notice that the force in question is clearly identified by a label in the diagram.
18	Q: [illegible] you have in fact also chosen D.	

	MAIN INTERVIEW FIVE		
Q#	**STATEMENT**		**COMMENTS**
18	A:	Oh well it's not in contact with the earth directly but if you mean gravity, um /// so clear .. because it doesn't come directly in contact with the earth, I mean the ground but if by that you mean gravity then it could also be acted upon by gravity because block A is being acted upon by gravity so indirectly it could be acted upon by B, by option B.	Recognizes gravity as the ulltimate origin of the force.
18	Q:	Okay and then C?	
18	A:	Um, I don't think C um because the string doesn't really have a force, it just has a tension between the force - the force of A, .. and, and the pulley .. so it - it's not its own; it could also have a force of friction against the pulley but er .. I don't think it's .. option.	Consistent with interpretation of question as asking for origin of force. Subject has answered according to an interpretation of the question not anticipated by the orginal researcher; thus false positive of linguistic origin.
20	Q:	Alright .. um alright then .. in number nineteen .. no let's skip number nineteen, um number twenty, you chose C.	
20	A:	This is because um .. um well if he's standing um on the moon then um he experiences a downward force because of er the moon's gravitational attraction but um because there are no other forces acting upon him, there's no air pressure or - or anything like that, so .. that should be the only force acting upon him.	Possible target misconception: `inability to identify forces'. I have my doubts whether this consitiutes a misconception according to my definition.
20	Q:	Okay, what about A?	
20	A:	Um, but even though there is no atmosphere there is a gravitational force so he does experience .. a force.	No target misconception.

	MAIN INTERVIEW FIVE	
Q#	**STATEMENT**	**COMMENTS**
20	Q: What .. what's the direction of air prcssure?	
20	A: Um down, downward.	Misconception confirmed.
4	Q: Um .. I'd just like to go back to question four; .. and your answer there's C. .. First of all why did you like C?	
4	A: Um .. because there is er .. if you drop a stone from a - a building there is a .. gravitational force .. it will speed up because um .. if it falls from a roof it doesn't have an initial er velocity so it will - it will speed up as it gains .. momentum.	No evidence of a misconception.
4	Q: Okay, what about er .. about B?	
4	A: I don't really know about that, `the gravitational pull increases as you get closer to the earth', I don't think that's .. true.	No evidence of target misconception.
4	Q: Mm-hm, okay and then A?	
4	A: Um .. I don't think off a single story building it will reach a maximum speed, I don't think there's enough time um to reach a max- a max- a maximum speed because um well terminal velocity, because um .. it needs quite a bit of time to reach a maximum speed .. so for that distance it will speed up but it won't reach a maximum speed.	Correct prediction for any case except perhaps an exceptionally light `stone'. No evidence of target misconception.
4	Q: Okay, and then finally here what about E?	
	END OF INTERVIEW.	

APPENDIX 3e: INTERVIEW TRANSCRIPT

	PILOT INTERVIEW TWO	
Q#	**STATEMENT**	**COMMENTS**
1	Q: Alright Ernest, could you outline your reasoning behind your first answer, that's question, the one about the two objects falling off the table.	
1	A: Well the two objects are at different heights, so they'll take er, different times to reach the floor; they like both have the same acceleration, but er just because its travelling different dis .. different distances they'll take different times, so that's why my answer was number `D', // ja .. A travels a shorter distance, so it reaches the floor first.	D was rated as evidence of a misconception by the original author. However this subject's explanation shows that he holds no misconception at all; he gives a correct prediction based on the data.
1	Q: OK, now what about the fact that the diagram clearly shows A travelling a further distance?	
1	A: Ja but .. er the.. the time, ah the question here is the time. The vertical distance is covered .. they both covered it in the same time .. the horizontal distance is covered in the same time .. ah well concurrently, so I don't think that there's any um .. well it would, won't it // the object will stop moving once the .. as it were it's used up it .. its height, that it has available to it to fall, and how far it moves horizontally in that time is irrelevant.	Subject shows that he fully understands the importance of the vertical component in the case involved; thus further confirmation that he holds no misconception and that his choice of option D is a false positive. As he has inserted the word `vertical' into his account (and his reasoning) means that he has edited the text of the question in such a way as to make better sense, thus the false positive is of linguistic origin.

	PILOT INTERVIEW TWO	
Q#	STATEMENT	COMMENTS
3	Q: OK, um, how long will it take the box to stop?	
3	A: I would have thought that it would have stopped instantly .. stopped immediately, I wouldn't have thought that it would have um .. continued .. taken a while for the friction to sto .. to slow it down to .. to zero velocity.	
3	Q: So .. let's confirm here, effectively you then mean when it s.. when they say the box will stop `suddenly', um that to you means `immediately'.	
3	A: As soon as the force is released.	
3	Q: OK now .. um .. what sort of a box did you envisage .. from their description, it simply says `a large box'?	
3	A: Now some sort of huge sort of case-sized object like a large travelling case that's being er .. that someone is sort of .. pushing across the floor and as then soon as they stop pushing it stops moving; that's what I .. that's the sort of object I visualised .. I didn't / visualise something small, like a matchbox [being] shoved across um the table um ..	
3	Q: And er what sort of frictional force would you have er thought this set-up would have?	
3	A: Well I can't actually um er quantify it ..	
3	Q: Well minimal, medium or relatively large?	
3	A: I would have thought relatively large.	
3	Q: OK what sort of surface is the box being pushed across; it simply says `a floor', now to your mind what does that say to you?	

	PILOT INTERVIEW TWO		
Q#	**STATEMENT**		**COMMENTS**
3	A:	Between 20 and 30 kilograms.	
3	Q:	OK now if the er box was being pushed across a smoother floor than the one you had envisaged, would that have affected your answer?	
3	A:	No .. no it wouldn't have .. I I would have .. I would have um .. because the question didn't say anything about friction, or considering friction I wouldn't have put that into my answer .. I would have .. my understanding, my concept is still as soon as the force is removed, the object will not move.	The box envisaged by subject, on the surface he describes would stop effectively immediately.
3	Q:	But with a smoother floor, would your .. I mean your own .. conception of the friction involved in the situation, would that have .. given you a similar sort of frictional force or a .. different one?	
3	A:	Oh much different; I mean well obviously the smoother the floor the ..um .. easier it is to push this thing and um the less the frictional force .. the lesser.. the smaller the frictional force acting against the .. the object is .. and er ja.	
3	Q:	OK, and er .. a box of I think you said 20 to 30 kilograms - got a fair amount of inertia, now if you took the frictional force, if you somehow reduced it like lets say we .. imagine that it's no longer just a smooth floor or a carpeted floor, but we're now on ice, where the friction has become minimal, and er there's now a fairly small force pushing the box but keeping it at a constant speed and you suddenly stop pushing ..	

	PILOT INTERVIEW TWO	
Q#	**STATEMENT**	**COMMENTS**
3	A: The .. well OK er, how .. the box has a velocity, moving at a particular velocity, constant velocity, as soon as the force is- is um removed from the box, not applied any more, um the friction between the box and the surface causes a deceleration and till eventually the er the box has no more velocity and it .. ja.. after a period of time it's actually it's the frictional forces acting against it to slow it down .. acting against the direction of motion that .. acceleration's in the opposite direction to the motion and the box eventually slows down to .. to zero velocity.	Repeat demonstration of correct Newtonian reasoning, thus confirmation that target misconception is not held by this subject. His choice was influenced by the great degree of interpretational freedom the lack of specification in the question stem allows the subject; i.e. the origin is linguistic.
6	Q: OK then I think I would like to skip.. think we can make this our final question .. to question 6, which I think is um .. worth discussing, unless we have time for another, it's the one about two people pulling on a box by means of ropes and you have selected answer `B' as your answer, what is behind that particular answer?	
6	A: Um .. OK I assume that the man is positioned at A, is pulling in the direction that that rope is facing so er then I would .. if- if just he were pulling .. I assume also that the man can pull more strongly than the boy so um that then B .. if- if it was to be at `C' OK that would indicate that they were pulling with equal strengths .. app.. applying the same sort of force, OK, `D' would imply that the boy was er applying more force `A' would imply .. position `A' would imply that the boy was exerting no force so I would choose `B' as a sort of average between the two.	Subject interprets question as envisaged by the original author. Correct Newtonian reasoning is being used.

	PILOT INTERVIEW TWO	
Q#	**STATEMENT**	**COMMENTS**
6/ 19	Q: So you read those as clues to the strength of the boy .. and the man. Alright then there's one final one I'd just try to deal with and that's number nineteen which is a .. question of 'which one of the following may not be a true statement about a body in uniform motion', and the answer you chose as .. was 'D'.	
19	A: 'Uniform motion' as I understand it is constant velocity; so if you have constant acceleration then you cannot have constant er constant e er velocity - if your body is continually increasing its velocity you can't have uniform motion; uniform motion as I understand it is constant velocity, that's why I thought that 'D' was inconsistent.	Subject's definition matches that of original author thus no misconception is held. However the original author would have regarded the choice of option D as evidence of a misconception.
19	Q: Now what about the possibility that *acceleration could be zero and* constant?	
	END OF INTERVIEW	