

University of Cape Town
Department of Physics

**Developing multi-representational
problem solving skills in large,
mixed-ability physics classes**

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A thesis submitted to the Faculty of Science at the University of Cape Town
in fulfilment of the requirements for the degree of Master of Science in Physics

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I declare that, except where acknowledged, the work contained in this thesis is my own original work, carried out with guidance and advice from my supervisor.

Signed by candidate

Gregor Leigh

29 March 2003

Abstract

First time entering students at South African technikons (even those enrolling for science courses) are typically characterised by having poor numeracy and problem solving skills coupled with poor attitudes towards learning physics. Their secondary education experience of physics has left them with little fondness or appreciation for the subject, which they perceive as a purely formula-driven, mathematical discipline with little or no connection to either their everyday experiences or their future careers. Poor first year pass rates at technikons are but one consequence of such attitudes and under-preparedness. Inappropriate epistemologies hamper life-long learning by precluding students from developing conceptual mastery and from assimilating valuable generic skills such as problem solving.

To address this situation, and the declining pass rates among Physics 1 students at the Cape Technikon, a new, research-based teaching strategy was introduced for the first year physics course in which multi-representational problem solving approaches were explicitly developed in order to provide an underlying foundation for the physics. It was found that more students were able to make appropriate use of the mathematical formulae needed to numerically solve a physics question after progressing through a series of non-mathematical representations of the particular problem situation. It was found that, as students' confidence improved, so too did their attitudes towards the subject. Post course testing showed a shift towards a more positive view of learning physics which also manifested itself in a higher pass rate in the Physics 1 course.

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Perhaps, to best prepare students for advanced work in science, engineering, and medicine, instructors of introductory physics courses should focus more on epistemological development and less on content coverage.

Andrew Elby (2001).

University of Cape Town

1. Introduction

1.1 Preamble

Students enrolled for any of several three-year National Diplomas in the Faculty of Applied Sciences at the Cape Technikon, Cape Town, South Africa are required take a semester course in physics. Besides providing a necessary foundation for other science subjects in the curriculum, Physics 1 is regarded as an appropriate arena in which to develop a variety of skills (both scientific and social), such as problem solving, numerical manipulation and cooperative group work.

Typically, however, technikon students are academically less robust than their university counterparts (some enrol after failing to gain entrance to a university). Poor learning skills, disadvantaged secondary schooling and unrealistic career expectations on the part of students are just some of the factors which militate against the success of the Physics 1 programme.

Traditional secondary school physics pedagogy concentrates on training students in the selection and manipulation of mathematical formulae using straightforward numerical data. Mastery of a few algorithmic procedures is usually sufficient to obtain a good Senior Certificate grade in physics. Most students who enter the Cape Technikon, however, have poor mathematics skills, and their experience of the formula-centred approach to school science leaves them with little confidence in their

own abilities. Consequently many have extremely negative attitudes towards physics. Furthermore, accustomed to the passive learning role they are encouraged to adopt in most secondary school classrooms, first year students often hold inappropriate epistemological beliefs about tertiary level physics.

The massification and transformation of tertiary education in South Africa during the 1990's further served to increase the percentage of first-year students who were ill-prepared for tertiary study, and the Physics 1 pass rate in the Faculty of Applied Sciences at the Cape Technikon dwindled to an average of 38% between 1998 and 2001.

For several reasons, including practical, financial, political and ethical considerations, an appropriate response in such circumstances is *not* simply “to ‘blame the victim’ or claim that ‘some students just can’t do physics’” (Redish *et al.* 1998, p. 223). Such a reaction would be “particularly destructive when ‘some’ turns out to be ‘most’”. Many students have had previous training in science and math classes that discourages understanding, questioning, and creative thinking” (p. 223). This is certainly true of Cape Technikon students where *most* of them have secondary school educational backgrounds which are *at least* as impoverished as those described by Redish *et al.*

Instead, the bulk of current physics education research suggests that it is the duty of instructors to modify their teaching strategies, both in response to the altered profiles and needs of their student populations and out of acknowledgement that “the task of the physics teacher today is to figure out how to help a much larger fraction of the population understand how the world works, how to think logically, and how to evaluate science” (Redish 2003, p. 7). Sheila Tobias refers to this as reaching the “second tier” of students – the “otherwise intelligent, curious, and ambitious young people” whose unhappy experiences of traditional science teaching cause them to believe that “there is no place for them in science” (Tobias 1990, p. 11).

While the “significant correlation between normalized learning gains and students’ pre-instruction mathematics skills” demonstrated by Meltzer (2002) appears to bode ill for the mathematically impoverished Cape Technikon students, Meltzer in fact uses

the finding to motivate for instruction more appropriate to the new generation of student: “However, the poorer expected outcome of using the *same* instruction with students of lower mathematics skill leaves open the possibility that different instructional methods and curricula might ultimately achieve the same levels of learning gain success with the new population as with the old” (p. 1266).

A concerted effort has been made during the past decade to apply findings from cognitive and physics education research to the design of models of physics instruction which take cognisance of both the demands of modern society and the characteristics of the modern student. Consequently there now exists “a large body of knowledge and a growing repertoire of curricula that are demonstrably more effective than our traditional approaches” (Redish 2003, p. iii).

Given that the art of problem solving is fundamental to the enterprise of both teaching and learning physics, it follows that many of these new models focus on strategies to convert “novice” problem solvers into “experts” through explicit instruction and training in the processes used by experts. Novices and experts differ both in the way their knowledge is organised and in the way in which they solve problems (Larkin *et al.* 1980), but since problem solving is widely accepted as “a powerful tool in assisting with changing and expanding the conceptual framework of the learner” (Buffler & Allie 1993), it is possible that explicit instruction in problem solving processes will also effect improvements in students’ knowledge structures and their ideas about the nature of learning.

Specifically (as regards this study), a number of physics education research groups in the United States have been experimenting with the development of multi-representational problem solving skills among freshman students enrolled for calculus-based physics courses at universities, and measuring the efficacy of such skill development in improving students’ attitudes to physics and their ultimate performance in the subject.

These approaches involve training students to defer the mathematical stages of problem solving by initially engaging qualitatively with the underlying concepts.

This is achieved by having them draw sketches, formal physics diagrams, graphs of motion and other visually-rich representations of problems *before* they introduce equations.

The results from these interventions have been very encouraging (Van Heuvelen 1991b, 1992b). Students given explicit training in multi-representational problem solving techniques consistently outperform students receiving “conventional instruction” in control groups. Most of these studies, however, were conducted on freshmen students enrolled for calculus-based physics courses at American institutions where certain minimum levels of mathematics competency are expected.

1.2 The present work

The present work is concerned with answering the following research questions:

In the context of a large, diverse, mathematically weak class in an algebra-based physics course, can explicit development of multi-representational approaches to problem solving promote positive attitudes towards learning on the part of students, thereby improving their performance on the course?

The study was conducted over two years on all students enrolled for the one-semester, algebra-based Physics 1 course in the Faculty of Applied Sciences at the Cape Technikon. Although the sample included students repeating the subject, the majority of the subjects were first year students, most of whom would have written their Senior Certificate examinations the previous year.

2. Research context

This chapter describes the Physics 1 course as one of several first year subjects in the Faculty of Applied Sciences at the Cape Technikon, and outlines the general teaching methodologies used in the course in the decade prior to 2002. A broad description of the socio-economic profile of Technikon students is followed by details of the specific pedagogical problems which prompted this investigation.

2.1 Physics 1 at the Cape Technikon

Physics 1 is a first semester subject which is compulsory for all first year students enrolled for three-year National Diplomas in Analytical Chemistry, Biomedical Technology, Food Technology, and Oceanography in the Faculty of Applied Sciences at the Cape Technikon, Cape Town, South Africa. For historical reasons, Chemical Engineering students from the Faculty of Engineering form part of the same group, so the fact that they are actually registered with a different faculty will be overlooked for the purposes of this study.

In addition to Physics 1, students must take between four and five other prescribed subjects during the same semester. Depending on the diploma, these may include Mathematics 1 (or a variation thereof, such as Calculations and Statistics), Chemistry 1, various other diploma-specific subjects (e.g. Introduction to Food

Technology; Anatomy and Physiology 1), and a range of support subjects such as Computer Skills and Communications Skills.

The lectures and practicals for these subjects are timetabled between 08:30 and 16:00 Mondays to Fridays out of consideration for the practicalities of student transport to and from the Cape Technikon campus, as the majority of students are resident off campus, with many using public transport to travel considerable distances (20 km to 50 km). First year student timetables are consequently full and intensive, allowing little time during the day for own study, or informal tutorial or group sessions. Typically, first year students in this faculty are scheduled for formal contact for 40 out of the possible 50 three-quarter-hour periods in a week. Biomedical Technology students have only five free periods a week.

Physics 1 is a 15-week-long algebra-based course which currently encompasses Newtonian mechanics, elementary thermodynamics, electricity and geometrical optics. In accordance with recommendations to “unstuff the curriculum” in the interests of a deeper understanding of a more manageable amount of material (Fox & Radloff 1996), the subject content has been gradually reduced during the past decade. Several topics (e.g. rotational motion, elasticity, hydrodynamics, the nature of light) and, in some cases, whole sections (e.g. electromagnetism and nuclear physics) have been discarded from the syllabus, while other sections have been simplified by restricting their scope of application. (For example: vector computation is limited to the addition of only linear or right-angled quantities; graphs of motion are almost entirely omitted; and projectile motion and momentum problems deal with only rectilinear situations.)

The result is a curriculum which, in terms of content, is broadly the same as the secondary school physics syllabi of Grades 10, 11 and 12. However, in order to comply with the Department of Education’s prescription regarding the level and pace of tertiary instruction in cases where a technikon instructional offering contains the same learning material as a pre-tertiary instructional offering, the material is covered over a shorter time and at a higher level than secondary school science. As stipulated, this requires “a greater degree of independent study and the acquisition of

comprehension and insight at a higher level on the part of the student than at the pre-tertiary level" (Department of Education 1997).

To pass Physics 1, students must obtain an overall mark of not less than 50%, made up of a year mark and a final three-hour examination mark which contribute 40% and 60% respectively to the total. To write the final examination a student must have attained a minimum year mark of 40%. The year mark is made up from several stipulated sources, including formal and informal tests, tutorials and laboratory work.

Table 1 shows how the several components of the Physics 1 course contribute to a student's overall mark. Bonus marks awarded for exemplary work in various activities such as reading quizzes (to encourage pre-instruction reading of texts) and small projects are not reflected here, but can contribute as much as an extra 10% to a student's year mark.

Table 1. Components of the Physics 1 course mark.

Activity		Marks	Sub-minima	
Year mark	Practical write-ups (best 10 of 12)	4%	40%	40%
	Practical examination (1)	4%		
	Weekly Problem Sets (best 10 of 12)	8%	-	
	Class tests (3 of approx. equal weight)	24%	-	
Final 3-hour examination on all theory (1)		60%	40%	
TOTAL		100%	50%	

"Contact time" each week consists of eight 35-minute periods (most of them combined into double periods and an occasional triple period) and a one-and-a-half-hour practical in the physics laboratories. As the aims and objectives of the laboratory component of Physics 1 are largely distinct from those of the theoretical classes, this component was not much affected by the new teaching intervention and will consequently not be discussed in this study.

All non-practical teaching (i.e. in so-called lecture periods) was carried out by the researcher himself, the sole Physics 1 lecturer in the faculty during the course of the investigation. (A part-time course tutor, or mentor, was employed in 2003 to assist with the implementation of a formal tutorial scheme.)

2.2 Physics 1 teaching style prior to 2002

Physics 1 at the Cape Technikon is a stand-alone, non-major subject – a “service course” aimed at providing fundamental scientific training to students and engineers who have no intention of becoming physicists. To some extent then, under the present lecturer the teaching emphasis in the course has always been on the development of scientific method and ways of thinking rather than on the transmission of new, or advanced academic content. Prior to 2002, however, instruction in problem solving techniques continued to focus on the mathematics-centred approaches traditionally taught in secondary schools. (The lecturer/researcher himself taught secondary school general science (Grades 8 and 9) and physical science (Grades 10 to 12) for fifteen years before joining the Cape Technikon.)

During theory classes the lecturer focussed on developing conceptual understanding using a combination of a limited amount of traditional “chalk and talk” exposition and small group discussions around carefully selected multiple choice questions specifically aimed at challenging students’ existing conceptions through processes such as cognitive conflict and bridging.

The same form of multiple choice questioning was used to assess conceptual understanding in tests and the final examination, making up between 35% and 40% of the total mark. The bulk of tests and examinations, however, comprised “traditional” numerical physics problems, at the end of which students were invariably expected to produce a numerical solution.

Prior to 2002 the lecturer spent very little time explicitly developing problem solving techniques in class. Furthermore, such instruction as there was consisted largely of

training students in the choice and manipulation of mathematical formulae (all of which are supplied in tests and examinations in the form of a booklet, together with tables of physical constants and other useful data). Very little attention was paid to a deeper, conceptual understanding of the physics behind the formulae themselves. Students were simply taught to “translate” ordinary language information (e.g. “The ball is dropped...”) into mathematical data ($v_y = 0 \text{ m/s}$), and then to choose the appropriate formula by studying the list of collected variable symbols and matching the list to one of the given formulae, before substituting the data and calculating the answer.

The Study Guide issued to Physics 1 students includes the following objectives, originally formulated in 1993:

After completing Physics 1 students should be able to:

- *Recall (as resources) certain laws, principles, concepts and formulae dealt with in this course.*
- *Apply these resources in the solution of numerical problems.*

The first objective was to a large extent waived owing to the practice of providing students with data booklets containing the required formulae. Furthermore, it was usually necessary to assist students with the second objective by breaking down the numerical problems in tests and examinations into sub-sections and “leading” students incrementally through the various stages of the problem until they could arrive at the final answer – the same procedure as is followed in Senior Certificate Physics examinations.

2.3 Student profile

First year students in the Faculty of Applied Sciences at the Cape Technikon generally have poorer Senior Certificate results and are less prepared for theoretical tertiary study than their counterparts at South African universities (some enrol after failing to gain entrance at a local university). They look to the Technikon to provide practical vocational training rather than a more abstract academic education. Although the Cape Technikon is currently preparing to reposition itself (after merging with another local technikon) as a “university of technology”, the overwhelming majority of students still regard the Technikon’s in-service training, or work experience component, as more useful and important than its post-graduate research opportunities.

While a few programmes (such as Chemical Engineering) are well subscribed, allowing programme convenors to hand-pick students on academic merit (based on Senior Certificate results), most other programmes, in order to ensure continuing viability, are obliged to accept virtually all applicants. Although minimum entry requirements stipulate that enrolling students should have passed Senior Certificate Mathematics and Physical Science – at least on the standard grade – some programme convenors occasionally admit students who last studied science and/or mathematics in Grade 9.

In addition to matters of expediency, the global trend of “massification” of tertiary institutions, amplified in South Africa during the last decade by affirmative educational practice (driven both by intrinsic reform and revised State subsidies), has also played a role in increasing the fraction of first year students who are inadequately prepared for traditional tertiary study.

Although the language of instruction is predominantly English (with Physics 1 course notes, tests and examinations issued in both English and Afrikaans), many students have English only as a second or third language after other South African and African languages such as Afrikaans, Xhosa, Tswana, Sotho, French, Portuguese and German (see Table 2 and Figure 1). However, poor English language and communication

skills are also becoming increasingly prevalent among first-language English speakers at the Technikon.

Figure 1 and **Table 2** illustrate the broad demographics of the samples. About two thirds of the students in each intake were female. About 80% were black (comprising 50% African, 29% Coloured and 1% Indian). Only about half the students were English speaking and another quarter were Afrikaans speaking. In each year group about a quarter of the enrolled students had failed Physics 1 at the Cape Technikon at least once before.

Table 2. Demographics of students enrolled for Physics 1 in 2002 and 2003.

		2002	2003
Gender	Female	129	181
	Male	63	107
Population group	African	79	141
	Coloured	68	85
	Indian	2	4
	White	43	58
Language	Afrikaans	49	64
	English	95	162
	Xhosa	33	41
	Other African languages	19	16
	Other non-African languages	1	5
Physics 1 enrolment	1st time	144	222
	Repeat	48	66
Total		192	288

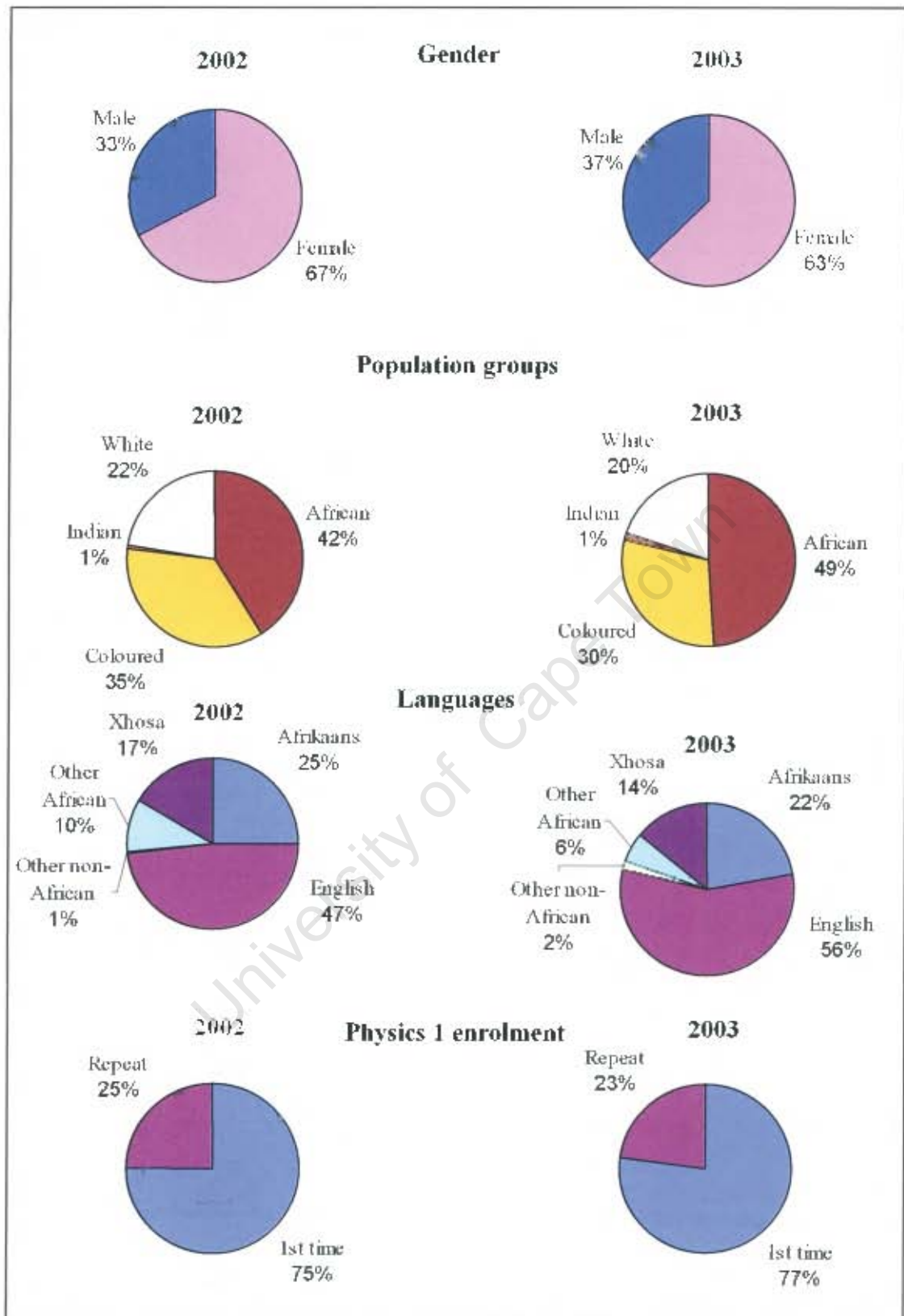


Figure 1. Demographics of students enrolled for Physics 1 in 2002 and 2003.

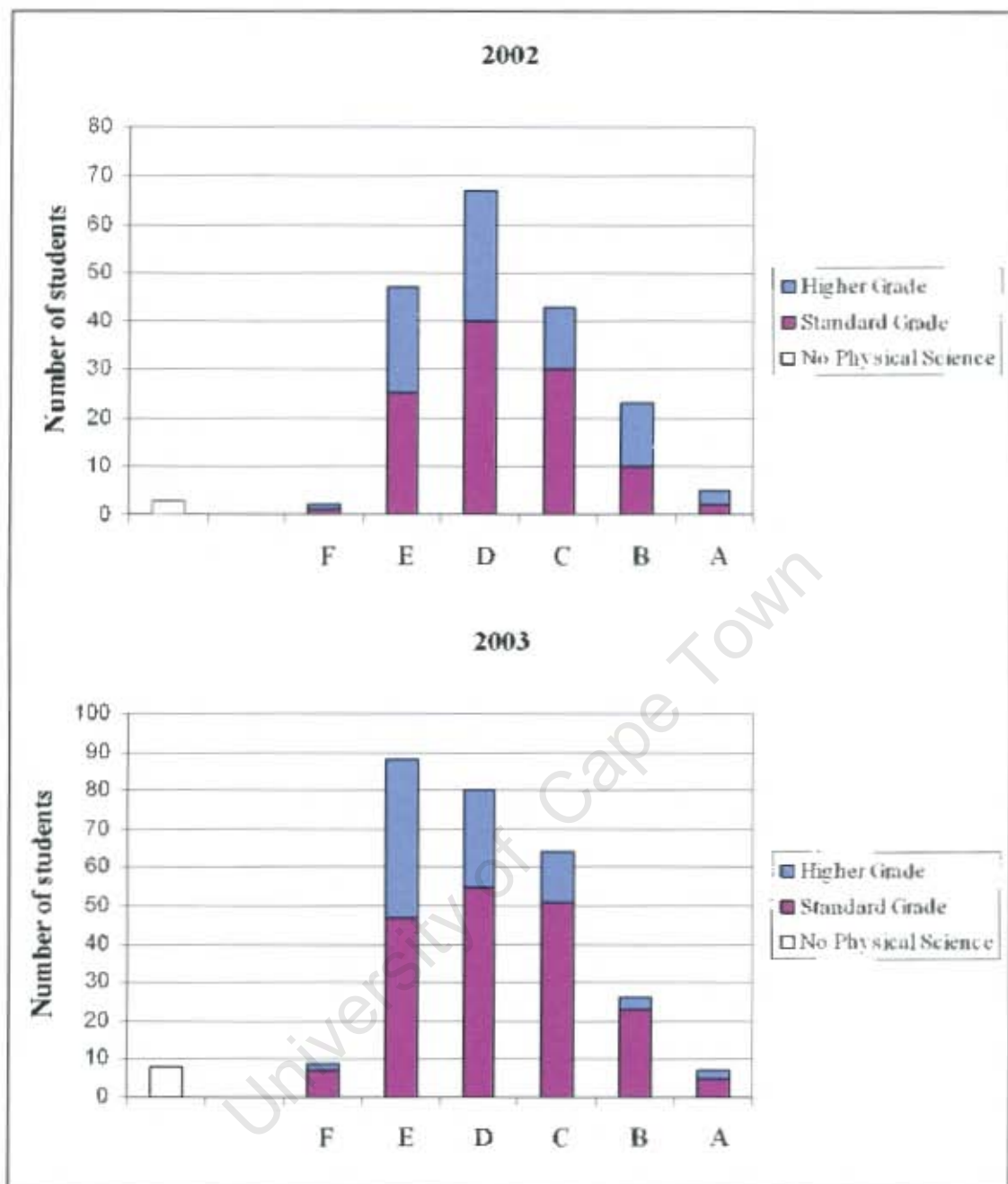


Figure 2. Senior Certificate Physical Science symbol distributions for students enrolled for Physics 1 in 2002 and 2003.

A comparison of the symbols achieved by 2002 and 2003 students in their Senior Certificate Physical Science examinations, as shown in **Figure 2**, reveals that the overall increase of student numbers in 2003 was due largely to extra numbers of students with Senior Certificate C, D and F symbols, particularly on the Standard Grade. The number of students enrolling for Physics 1 with Higher Grade A, B and C symbols for Senior Certificate Physical Science dropped significantly in 2003.

While a very small percentage of black students are from other (usually African) countries and a few others attended good schools in South Africa, most of them (and a number of coloured students) come from educationally disadvantaged backgrounds, characterised by a lack of qualified science teachers and poor facilities. These students are thus generally poorly trained in scientific thinking processes (such as problem solving) and hold naïve epistemological beliefs about the subject.

Furthermore, most of the Cape Technikon students are “first generation” tertiary learners, that is, they are the first members of their families (even extended families) to study beyond secondary school (sometimes even primary school) level. The particular stresses and problems encountered by such students as they adapt to a completely new cultural environment and its academic demands are well documented (Cliff *et al.*, 2003; Terenzini *et al.*, 1996; Zipin & Brennan, 2001). At best, students can expect only inexperienced, uninformed moral support from their families, and are forced to learn even the most basic of tertiary skills purely through first-hand (sometimes bitter) experience. At worst, several parents are sceptical, or even openly antagonistic, about their children’s educational aspirations, believing that they should rather enter the workforce immediately in order to be able to contribute financially to the family welfare, instead of being a further drain on limited financial resources.

As a result of current events in South Africa such as the AIDS pandemic and relatively high levels of violence, an increasing number of students are being forced into assuming unnatural family responsibilities at a time when they should be allowed to concentrate solely on their own studies. Several students are family breadwinners and find themselves *in loco parentis* for families of orphaned younger siblings, whose care must often take precedence over students’ academic studies.

Whether their families are unable, or unwilling, to provide support, many Cape Technikon students have to make their own arrangements for the payment of fees (sometimes both academic and residential). This typically involves spending a considerable amount of time applying for bursaries, as well as looking for, and then undertaking part-time work. Under these circumstances students, who typically lack

time-management skills, find it difficult to accord adequate time to their studies, or they operate on too little sleep to be fully attentive and receptive during class.

Other students are dispatched off to technikon with the combined financial support and blessings of an entire community – an arrangement which places an extra, unnatural and stressful burden of responsibility on the recipient.

In both cases, whether students receive outside funding or are paying their own way, academic failure carries more than the usual psychological implications of negative self-image and diminished confidence. It is very difficult to convince such students to relinquish the methods of secondary school – especially if such methods produced a reasonable grade, irrespective of whether any real understanding or development occurred. New methods of learning require experimentation and practice, and are seldom immediately successful. The serious financial implications involved discourage many students from taking the necessary risks.

Most students, whether they come from disadvantaged schools or not, have been conditioned during secondary school education to see physics as purely an exercise in the manipulation of mathematical formulae. Aside from according a few marks to the straightforward recall of laws and definitions, school tests and examinations (including the final Senior Certificate examination) reward students who can recall appropriate formulae, substitute given data and produce numerical answers. Students whose mathematics is functionally weak perform poorly with this approach and struggle to see the forest of physics for the trees of mathematics. Such secondary school experience leaves many students with little confidence in their own abilities and a fear or hatred of physics.

Other students, having achieved some measure of success with the mathematical approach, are reluctant to abandon the methods and attitudes which earned them good marks in their final Senior Certificate examinations. They continue to expect to be rewarded for merely applying formulae and calculating numerical answers to problems, and are often unwilling (or unable) to develop the deeper conceptual understanding of physics required at tertiary level.

The fact that Physics 1 (the *only* physics requirement for the National Diploma courses) is a stand-alone, single semester offering further contributes to the poor motivation of Cape Technikon students towards what is regarded by many as their most difficult and problematic first year subject.

The foregoing description concentrates on those characteristics of technikon students which set them apart from other first year tertiary groups, such as university students on calculus-based physics programmes, but it is important to take cognisance of the fact that, as this population comprises mostly 17- to 21-year-old first time entering students, it also manifests, as expected, other well-documented attributes universally typical of first year, novice physics students, namely:

- tenaciously held preconceptions (which are often inappropriate, and hence constitute a hindrance to further development and insight);
- a lack of well-organised, “chunks” of conceptual knowledge;
- difficulties interpreting written and aural input (e.g. from texts and lectures);
- various deficiencies in generic study-skills such as note-taking, time management and test preparation.

All of the above characteristics had to be taken into account when choosing an appropriate teaching strategy.

2.4 Further problems

During the years immediately prior to 2002 several specific problems relating to students' experience of, and success in, Physics 1 became more prevalent and noticeable.

2.4.1. Increasing class size

Physics 1 class sizes increased at the end of the 1990's owing both to the Cape Technikon's deliberate policy of massification and to the increasing number of students repeating the subject as a result of having failed it (up to four times) previously.

As declining first year pass rates began impacting on second and third year student numbers, programme convenors reacted by increasing the first year intake in an attempt to maintain course viability. They admitted as many first year students as they could, often with little regard for their academic ability or tertiary readiness.

The larger class sizes held all the usual implications for student performance, as individual students were forced to compete for diminishing amounts of individual attention, or simply became lost in the system. Weak students who in the past might have succeeded with extensive one-on-one assistance were now being neglected as stretched resources were focussed on even weaker candidates.

2.4.2. Declining academic competency

Despite reductions in subject content, and several educational interventions and innovations (e.g. the introduction of student tutors, cooperative learning strategies, the issue of data booklets in examinations, bonus mark incentives for reading the texts ahead of lectures), the pass rate in Physics 1 deteriorated from an average of 60% between 1993 and 1997, to 38% between 1998 and 2001.

Tests and examinations revealed that while attempting to solve physics problems students were more and more frequently...

1. choosing inappropriate formulae (e.g. consider the student solution to a question based on Archimedes' principle shown in **Figure 3**);
2. mixing up physical quantities in formulae (e.g. attempting to equate $\Delta Q =$ heat energy with $Q =$ amount of electrostatic charge, or, as in **Figure 3**, $c =$ speed of light with $c =$ specific heat capacity);
3. making elementary mathematical errors – including improper use of the equals sign (see **Figure 3** and **Figure 4**);
4. presenting incomplete answers (e.g. forgetting to include the directions of vector quantities);
5. presenting unreasonable answers (revealing an inability or unwillingness to perform logical checks with reference to the original problem statement, e.g. “The height of the atmosphere was calculated to be 9.9 mm.”).

<p>2.3.2 If a lump of metal weighs 2.50 N in air and 2.22 N when completely immersed in water, identify the metal.</p>
<p>2.3.2. $F = mg$ $2,50 = m \times 10$ $\therefore m = 0,25 \text{ kg}$</p> <p>$E = m \cdot c^2$ $E = 0,25 \text{ kg} \cdot 4200$ $E = 1,05 \times 10^6$ $E =$</p> <p>\therefore The metal = Granite</p>

Figure 3. Mistakes made by a student while attempting to solve an Archimedes problem in a test. Einstein's formula appears in the students' data booklets, but is not referred to in the course and is completely inappropriate in this context. Furthermore, the student has confused $c =$ speed of light with $c =$ specific heat capacity. Units are used only sporadically and inconsistently, and improper use is made of the equals sign.

2.3 A steel plug has a diameter of 10.000 cm at 30°C. To what temperature must it be cooled in order to fit into a hole with a diameter of 9.997 cm?

2.3

$$\begin{array}{r}
 10,000 \\
 \underline{9,997} \\
 0,003
 \end{array}$$

$$\begin{aligned}
 0,003 &= 1,2 \times 10^{-5} \times 10 \\
 0,003 &= 0,000012 \\
 &= 30^\circ - 25^\circ \\
 &= 5^\circ
 \end{aligned}$$

Figure 4. Another example of poor computation by a student. Following a childish long method of subtraction, the student omits the appropriate formula and proceeds directly with a “calculation” which is rendered nonsensical through misuse of the equals sign.

Where complex questions were not broken down into sub-sections, in order to “lead” students incrementally through the various stages of the problem (as is done at secondary school level), it was found that increasingly few students were able to analyse the problem and work their way through to the final answer on their own. In other words, students were able to cope only with one-step problems, and showed little aptitude for dealing with problems requiring multi-step algorithms.

Furthermore, it was found that more students were experiencing problems with language, and were disregarding instructions and misinterpreting questions. Key words sometimes triggered naïve and incorrect responses, for example where students set out to calculate a *distance* in response to a question which read “How long would it take...”.

2.4.3. Lack of specific training in problem solving techniques

Traditionally, at secondary school level (and often at tertiary level as well), physics students watch passively as the teacher (expert) – instinctively and without comment

– applies a host of problem solving skills which are not immediately apparent to the student (novice). Students are then expected to develop insight and experience by simply mimicking this behaviour, repeatedly practising the demonstrated algorithms until understanding “occurs by itself”.

Lecturers of first year students are wont to assume that their students have already learnt the pre-requisite problem solving skills at secondary school level, despite mounting evidence to the contrary. Indeed, prior to the new outcomes-based curriculum prescribed by the Department of Education in the late 1990’s, the South African high school science curriculum “was not explicitly designed to develop critical thinking and problem solving” (Hobden 2002).

2.4.4. Deteriorating attitudes towards physics and learning

Massification impacts on students’ attitudes to physics. Creating and sustaining a “culture of learning” is difficult in a milieu containing very few traditional scholars. While conditions in the townships and informal settlements from which many students come militate against academic study (both physically and socially), even homogeneous concentrations of students in campus residences have proved resistant to attempts to establish the necessary academic ethos (Mpuru 2003).

Soon after extra physics tutorials (run by specially trained peer tutors) were implemented towards the end of the 1990’s, attendance at tutorials began declining until, in 2003, less than 10% of the Physics 1 class was making use of the service. Cape Technikon tutors are specifically trained (by the Student Tutoring Services department) not to re-teach the material and to avoid simply giving students the answers to problems set by the lecturer and the tutors themselves. Their explicit function is simply to facilitate discovery on the part of students and to guide them in the construction of their own schemata. Feedback from those few students who did take the trouble to attend indicated that the service was inherently useful, while many of those who did *not* attend complained that the exercise was pointless because answers were not given and the tutors “refused to teach” them.

In formal, written, anonymous student feedback at the end of each semester, a growing number of students were indicating dissatisfaction with the subject and the lecturer. A similar complaint to that levelled against tutors was prevalent here too: “The lecturer refuses to teach us”, underlining the naïvety of some students’ epistemological expectations. As a result of underestimating the amount of personal practice required, and failing to understand the importance of constructing their own knowledge, students confused teaching (exposition) with learning (mastery). They were suspicious, even resentful, about the disparity between “how easy the lecturer makes it seem in class” and the confusion and uncertainty they experienced when required to solve problems (even the same ones) on their own. They were also genuinely puzzled as to why the algorithmic methods which had worked at secondary school level were no longer sufficient or effective.

Some students resigned themselves to the conviction that the subject was too difficult for them – or at least that the lecturer was deliberately and maliciously “making” it too difficult for them. They gave up trying, and relied on eventually being “put through”, after several registrations (sometimes without attending any classes), on the strength of having passed other (content) subjects, or, sometimes, through the intercession of a sympathetic programme convenor.

Such negative shifts in attitude towards the subject were closely related to the increasing number of repeating students in Physics 1 classes (6% prior to 1998; 17% between 1998 and 2001; 24% in 2002 and 2003). Besides impacting on class attitudes to physics and the ethos of the classroom, the increasing number of repeating students was contributing to the declining pass rate, as many students who fail Physics 1 the first time do not improve or alter their study methods before they attempt the subject again. Once again it was a moot point as to whether students were being given adequate, explicit training in the necessary methods and problem solving strategies, or whether “the problem of *acquiring* the requisite skills [was simply being] left to [their] ingenuity, good fortune, and native ability” (Kurfiss 1988, p. 4).

2.4.5. The pictorial paradox

There is now substantial evidence that important learning processes dealing with verbal and linguistic interpretation (both written and aural) are processed by the left hemisphere of the brain (Lord 1984; Zhang 2002). Modern first year students, however, as a result of being “influenced, taught, manipulated by all kinds of visual information, including television, computers, signs, and symbols, advertisements, body language, and motion picture films” (Hortin 1994, p.5), tend to favour right cerebral hemisphere processes – at the expense of left brain development.

In practice this means that, as a result of years of conditioning by predominantly visual stimuli, current first year students are ill-equipped for studying from written texts, or for interpreting traditional verbal teaching formats which are still directed to the verbal-analytical functions of the left brain. They are better “programmed” to process holistic, pictorial information.

Paradoxically, however, despite this predisposition towards visual information, students appear reluctant or unable to produce their own pictorial representations in order to gain better insight into the nature of physics problems and their underlying concepts. Informal, unstructured attempts prior to 2002 to get students to “sketch the situation” inherent in a problem prior to assembling the numerical data met with a great deal of resistance. Very few students seemed prepared to even attempt the strategy.

Van Heuvelen observed similar reluctance (1991a) and offered three reasons for it: lack of understanding of the basic physics quantities and concepts; lack of prior explicit instruction in pictorial practice; and unresolved conflict arising from persistent misconceptions (and faith in previously successful strategies).

3. Benchmarking students' initial knowledge states

The present study was conducted on first year students enrolled for Physics 1 in the Faculty of Applied Sciences at the Cape Technikon during 2002 (192 students) and 2003 (288 students), although several characterisation studies were also performed on earlier intakes.

3.1 Benchmarking instruments

At the start of the physics semester course, several tests were used to measure students' individual levels of numeracy, scientific reasoning and epistemological beliefs, and to identify their preferred problem solving strategies. With the exception of the test for scientific reasoning, the tests were administered to the whole group, but where students were absent for either a pre- or post-instruction test their scores were disregarded in order that only *matched* data should be reported.

- (a) *Numeracy* – students' ability to understand and process numerical information was tested using a home-grown basic numeracy quiz in 2002 and a more formal and validated numeracy questionnaire in 2003;
- (b) *Scientific reasoning* – students' concrete- and formal-operational reasoning abilities were scored using a validated pencil and paper quiz;

- (c) *Pre-existing problem solving strategies* – in addition to students' responses to class examples and tutorials, a specially designed open-book test containing four kinematics problems of increasing complexity was used to identify and catalogue students' initial problem solving strategies.
- (d) *Epistemologies* – students' attitudes to physics and their expectations of teaching and learning in the subject were assessed using a written physics expectations survey.

Other instruments were used during the course of the semester's instruction to monitor changes, particularly changes in students' epistemological beliefs and their problem solving strategies (see Section 5.1).

3.1.1. Benchmarking students' initial numeracy skills

The importance of students' pre-instruction mathematics skills as a predictor of their learning gains in physics has been revealed in a recent study by David Meltzer of Iowa State University (2002). While their initial levels of conceptual knowledge appear to play little part in students' ability to master the subject, by contrast, their scores on pre-instruction mathematics assessment are shown to be significantly correlated with their normalised learning gains (Meltzer 2002).

(a) Baseline Mathematics quiz

The Baseline Mathematics quiz (Appendix A) was developed to measure students' initial competencies in several distinct areas of mathematics, including general numerical skills, algebraic manipulation, spatial perception, logic, estimation, calculator proficiency and graphical literacy. The quiz comprises 30 multiple choice questions drawn largely from Grade 4 and 5 South African Mathematics Olympiad papers, and was administered to all Physics 1 students at the beginning of each first semester between 1999 and 2002. Administering the same quiz over four years allowed for the validation of questions and the observation of annual trends.

(b) Numeracy Competency Questionnaire

In 2003 the Numeracy Competency Questionnaire (NCQ2003) (Frith *et al.* 2003a), designed by the Numeracy Centre at the University of Cape Town as part of its Effective Numeracy course (Archer *et al.* 2002), was administered to incoming Physics 1 students. This instrument has been thoroughly validated, having been applied already to several other tertiary student groupings, including both Humanities and Science students at the University of Cape Town, and elsewhere, making it possible to benchmark the Cape Technikon students against these groups.

The NCQ seeks “to establish the numeracy level of participants in some of the skills which have been identified as the basic tools of quantitative literacy” (Numeracy Centre 2003).

The Numeracy Centre’s defines quantitative literacy as follows:

“Quantitative (Mathematical) Literacy is the ability to manage situations or solve problems in a real context, and involves responding to quantitative (mathematical and statistical) information that may be presented verbally, graphically, in tabular or symbolic form. It requires the activation of a range of enabling knowledge, behaviours and processes and it can be observed when it is expressed in the form of a text (which we define in the largest sense as communication, in written, oral or visual mode).” (Numeracy Centre 2003).

This definition emphasises that the questionnaire is not merely a re-test of school mathematics, but a more fundamental probe into students’ ability to function effectively in society by making adequate sense of the mathematical data which surround them in the everyday world.

The Numeracy Competency Questionnaire consists of three distinct multiple choice sections, all of which are designed to be answered without the use of calculators. It is a proprietary instrument which is kept secure by the University of Cape Town

Numeracy Centre in order to maintain its validity from year to year, and for this reason it is not possible to include a copy of the NCQ2003 document in the present work. However, **Table 3** describes in broad terms the content and testing aim of each section of the questionnaire.

Table 3. *Content and testing aims of the Numeracy Competency Questionnaire (NCQ2003).*

Section A	Questions testing basic numeracy, mostly involving fractions, decimals and percentages.
Section B	Questions around a central theme and involving the use of diagrams, tables and graphs. The questions test literacy and interpretative skills more than in the first section, and provide an opportunity for participants to demonstrate their ability to handle quantitative literacy.
Section C	An example of the application of “everyday” numeracy. This section also tests the understanding, use and construction of formulae in “everyday” situations.

3.1.2. Investigating students’ initial scientific reasoning abilities

Formal reasoning skills play a significant role in traditional tertiary level science programs since “students who are still reasoning at the concrete level are able to learn very little, if any, of what is taught in an abstract, verbal way” (Lawson 1978, p. 21).

The Classroom Test of Scientific Reasoning (CTSR, Appendix B), adapted from the pencil-and-paper version of Lawson’s test of formal reasoning (Lawson 1978), was administered to samples of Physics 1 students in 2002 (N = 49) and 2003 (N = 97) in order to assess Cape Technikon students’ concrete- and formal-operational reasoning abilities. The samples each consisted of a single, coherent class and were deemed to be representative enough of the whole group to render more extensive testing superfluous.

The original test, involving live demonstrations with real equipment, was developed as “a reliable and valid classroom test of developmental levels – specifically, formal-level reasoning” (Lawson 1978, p. 11) without the need for trained psychology interviewers. The later, pencil-and-paper version has also been validated (Lawson 1987), and was chosen because it is logistically more feasible for assessing large classes.

In the test, students are posed questions or asked to make predictions regarding concrete examples of physics and mathematical principles (e.g. whether the mass of an object changes if its shape changes), and are further required to justify or explain their answers. Items are marked correct only if the correct answer *and* an adequate explanation are given.

On the basis of their scores, students are categorised on an adapted Piagetian scale of intellectual development as “concrete operational” (empirical/inductive) thinkers, “transitional”, or “formal operational” (hypothetical/deductive) thinkers (Lawson 1992). The categorisation results of the Cape Technikon students were then compared with the results of a group of first year physics students in the United States reported by Lawson (1992).

3.1.3. Investigating students’ initial problem solving strategies

Prior to instruction in 2002, students were given a specially designed diagnostic test (**Figure 5**) in order to determine the extent to which they used pictorial representations, formal physics diagrams, and/or mathematical formulae during problem solving. The test consists of four kinematics questions of increasing complexity. All the questions involve rectilinear scenarios, but, aside from the first one, are bi-directional, and become increasingly difficult to solve by sole reliance on the implementation of equations of motion.

Kinematics Test

1. How long will it take a car to reach a speed of 30 m/s if it accelerates from rest at 5 m/s²?
2. At what speed does the yellow “jumper” leave the table if it is in the air for 1 s?
[This question was accompanied by a demonstration.]
3. A man on the edge of a building 50 m above street level shoots a bullet straight up into the air at 45 m/s. How long after he fires the gun does the bullet land in the street?
4. Andile and Zoe need to swap books, but her residence is locked for the night. So he stands below her first floor window (5 m up) and throws his book up to her at the same time that she drops her book. If Andile threw his book up at the same speed with which Zoe’s book eventually hit the ground, at what height did the books pass each other?

Figure 5. Diagnostic test used to determine students’ initial problem solving strategies.

The test also served as a natural springboard for the introduction of more effective problem solving strategies, viz. those based on multi-representational approaches.

3.2 Benchmarking results

The results of each of the aforementioned benchmarking tests are presented below.

3.2.1. Initial levels of numeracy

(a) Baseline Mathematics quiz

Figure 6 shows the distribution of Cape Technikon Physics 1 students’ scores in the Baseline Mathematics quiz between 1999 and 2002.

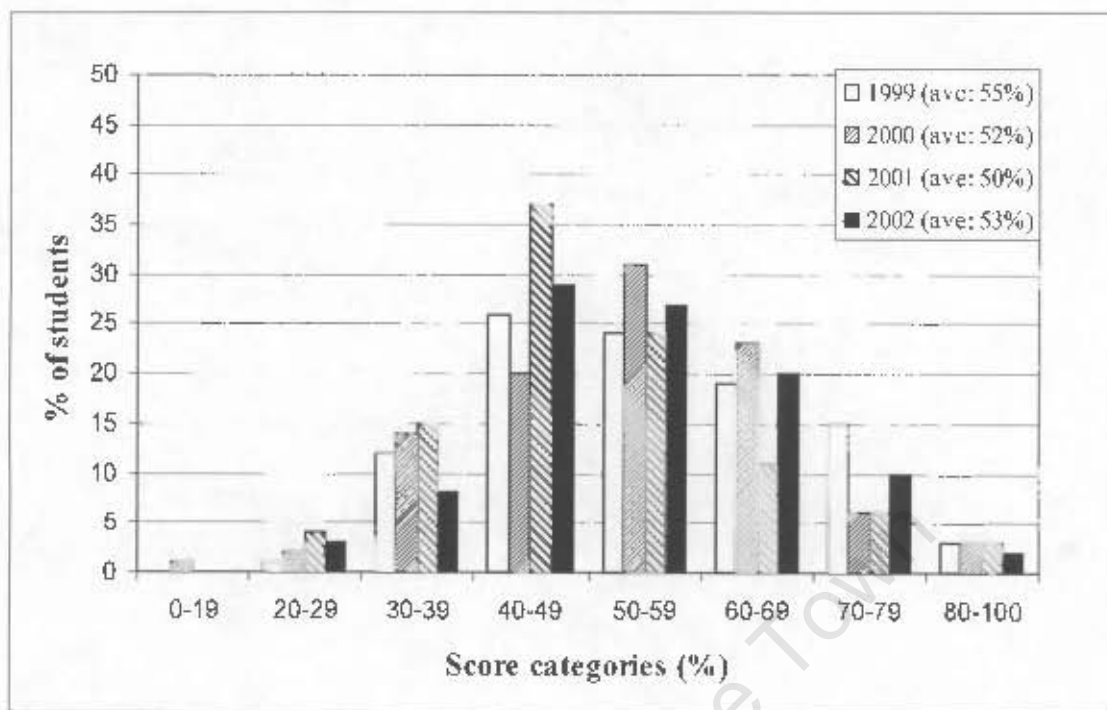


Figure 6. Percentage distribution of the scores of Cape Technikon Physics 1 students' in the Baseline Mathematics quiz between 1999 and 2002.

The four year survey reveals that students' basic numerical abilities remained at a roughly constant level during the period, with the overall test average ranging between 50% and 55%, and the mode usually lying in the 40-49% range. Fewer than 5% of students in any year were able to achieve 80% or better in the test.

(b) Numeracy Competency Questionnaire

The results of University of Cape Town's Numeracy Competency Questionnaire (NCQ) for 2003 are shown in Table 4 and Figure 7. The Cape Technikon students performed worse than any other group tested up to that stage (which included both Humanities and Science students at the University of Cape Town). While UCT means ranged between 57% and 71% (with the lowest third quartile at 69%), the overall average for the Cape Technikon group was 46%, with three quarters of the students scoring below 57%.

Table 4. Cape Technikon Physics 1 students results by section (refer to Table 3), and overall, in the UCT Numeracy Competency Questionnaire (NCQ2003) (Frith et al. 2003b).

	Mean	Median	Min	Max	1 st Quartile	3 rd Quartile	Std Dev
Section A (easy questions)	51%	51%	5%	95%	33%	69%	21%
Section B (graphic interpretation)	45%	44%	10%	94%	35%	54%	14%
Section C (“everyday” numeracy)	39%	37%	0%	89%	26%	52%	18%
Overall	46%	45%	11%	85%	34%	57%	15%

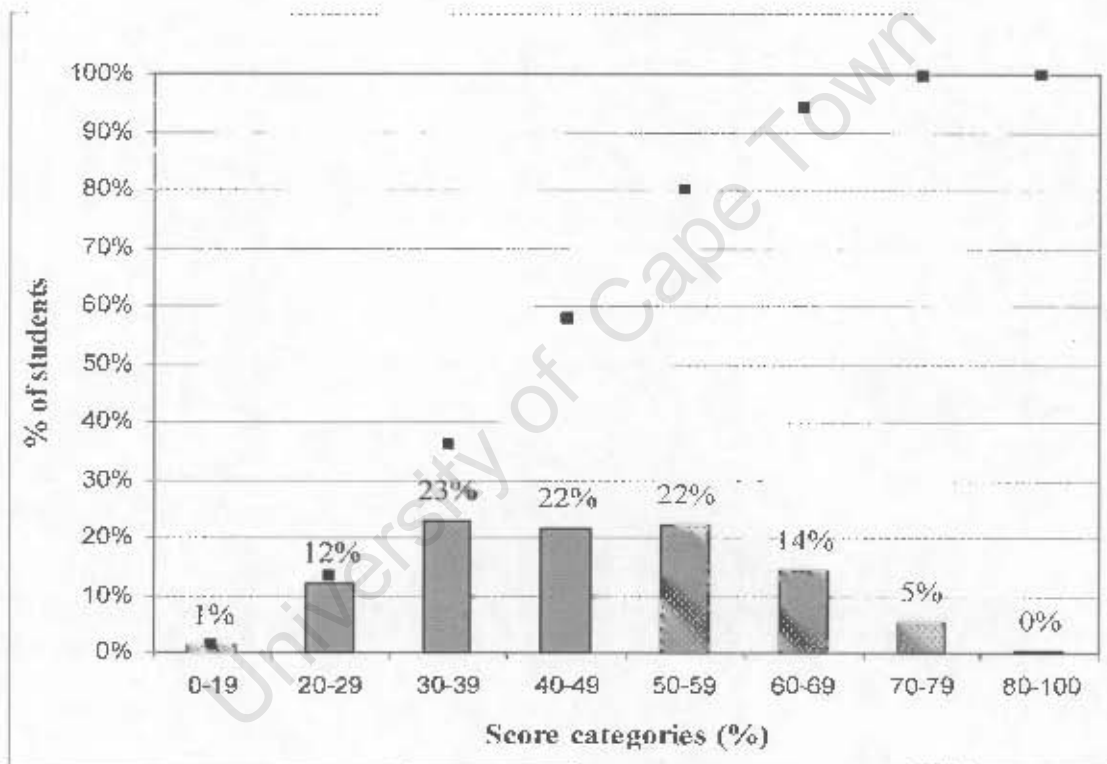


Figure 7. Percentage distribution of Cape Technikon Physics 1 students' overall scores on the University of Cape Town's NCQ2003 (Frith et al. 2003b).

An important feature of these results is the small percentage of students achieving 60% or more for the quiz. Based on previous testing of other tertiary student groupings, the Numeracy Centre advises that “an overall score of 60% appears to indicate a satisfactory basic level of numeracy for students intending to follow a Humanities program at a University, whereas a score of 70% would be more appropriate for students intending to study in a Science faculty” (Frith et al. 2003b).

According to the designers of the NCQ, fewer than 5% of the 2003 Cape Technikon students had numeracy skills appropriate for a course of study in the Faculty of Applied Sciences.

The results for Sections B and C are of particular significance for physics students. Section B tested students' ability to apply quantitative literacy skills in integrated and relevant contexts, while Section C tested (*inter alia*) students' ability to work with formulae. Much of first year physics consists of applying mathematical skills in different physical contexts, and (besides being a necessary life skill) the manipulation of formulae is central to the solution of many physics problems. Students who perform poorly in these sections can be expected to experience serious difficulties with the mathematical aspects of the physics course.

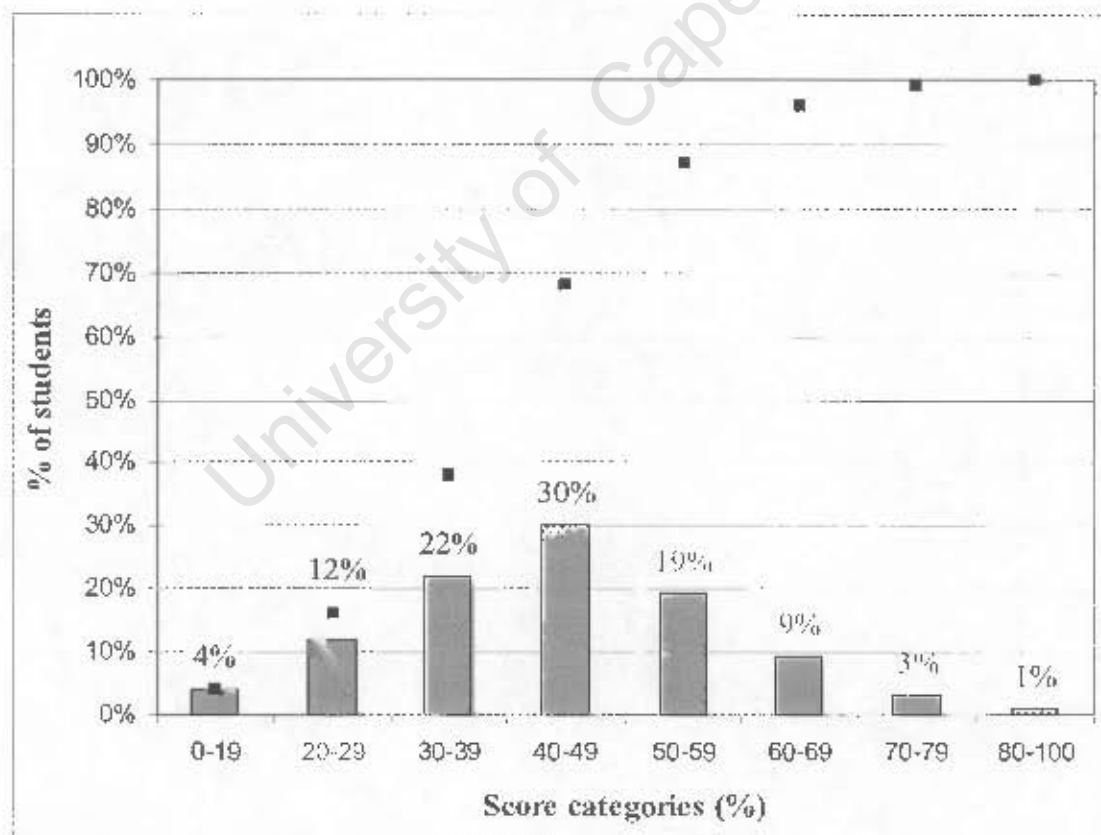


Figure 8. Percentage distribution of Physics 1 students' scores in Section B of the University of Cape Town's Numeracy Competency Questionnaire (NCQ2003) (Frith et al, 2003b).

The percentage distribution of scores in Section B of the NCQ (Figure 8) shows that most of the Cape Technikon students scored fewer than half of the marks for questions involving the interpretation of tables and graphs. Figure 9 shows that students fared very poorly in Section C, with most of the group attaining less than 40% for the section (which contained questions based on the use of mathematics in “everyday contexts”).

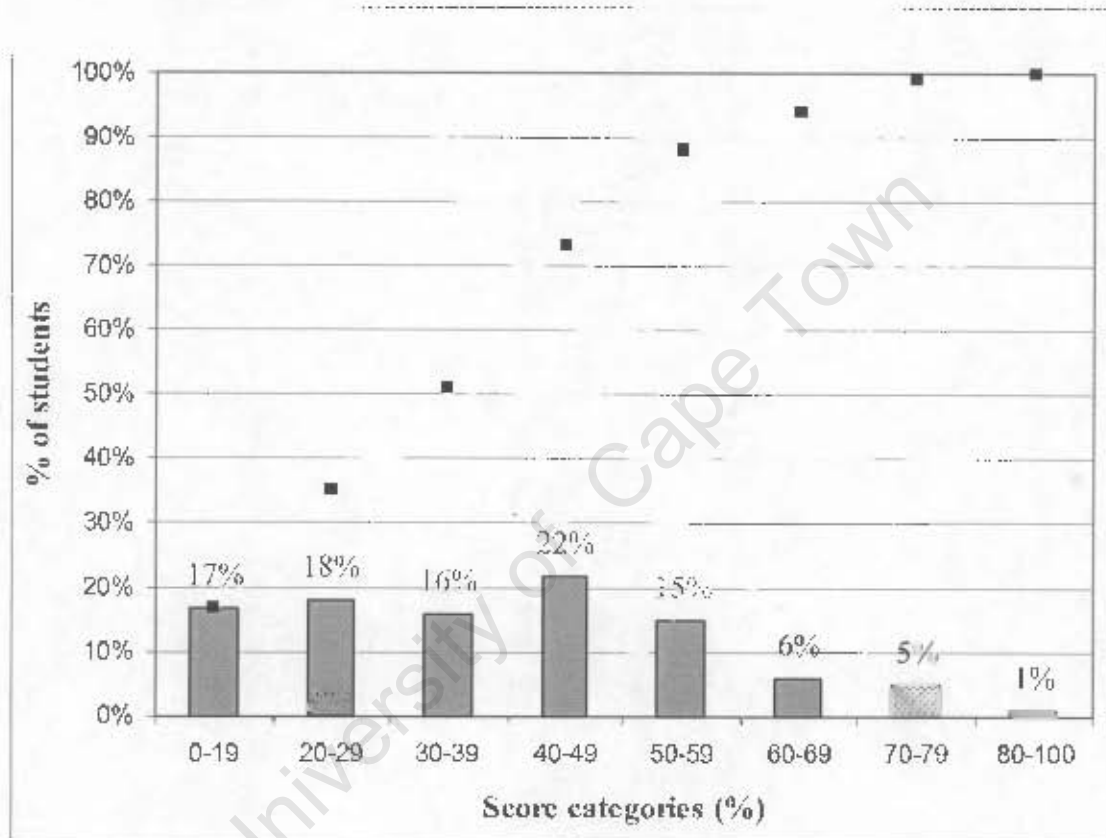


Figure 9. Percentage distribution of Cape Technikon Physics I students' scores in Section C of the University of Cape Town's Numeracy Competency Questionnaire (NCQ2003) (Frith et al. 2003b).

Certain questions uncovered the students' specific shortcomings in basic mathematical processes which play a vital role in physics problem solving:

- decimal fractions – fewer than half the students were able to correctly rank numbers which contained decimal fractions;
- approximation – fewer than 30% of the students were able to perform a calculation which involved approximation;
- percentage – the majority of questions involving percentages were correctly answered by fewer than 50% of the students (in several questions by fewer than 20%);
- ratio and proportion – only 29% of students were able to work out a number from a given ratio of two numbers and their total;
- formulae – of the six questions involving the use and manipulation of formulae only one (involving straight application/substitution) was correctly answered by more than half (51%) of the students. Only 47% of students were able to change the subject of a formula, and only 17% showed ability in constructing a formula from information given in the text.

3.2.2. Initial levels of scientific reasoning

Figure 10 shows the results of the Classroom Test of Scientific Reasoning (Appendix B) applied to the sample of 97 Cape Technikon students in 2003, compared with the results from a group of 922 non-physics major freshman-level biology students as reported by Lawson (1992).

Students who score between 0 and 4 out of 12 for the test are deemed to be at the empirical/inductive level of thinking according to Lawson's summary of Piagetian development; those who score between 5 and 8 are transitional; and those who score 9 and above can be regarded as having reached the hypothetical/deductive level.

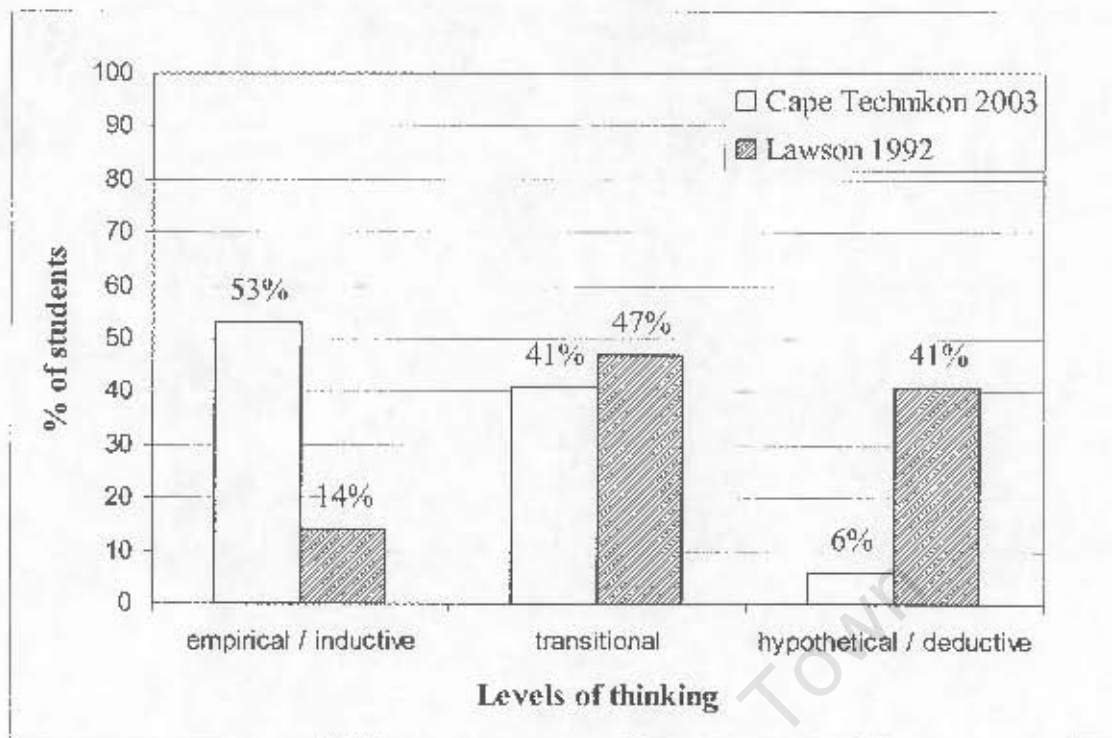


Figure 10. Distribution of Classroom Test of Scientific Reasoning scores according to Piagetian thinking development category. Cape Technikon Physics I 2003 students scores are contrasted with those of a group of United States non-physics major freshman-level biology students tested by Lawson (Lawson 1992).

With more than half the sample still reasoning at the empirical/inductive level (and therefore, according to Lawson “able to learn very little, if any, of what is taught in an abstract, verbal way” (1978, p. 21), these results suggest that the majority of Cape Technikon Physics I students are under prepared for a traditional tertiary physics course.

3.2.3. Students’ initial problem solving strategies

Almost all students treated each problem on the introductory/diagnostic kinematics test (Figure 5, Section 3.1.3) as a fundamentally mathematical exercise (See Figure 11, Figure 12 and Figure 13), translating the given verbal information into numerical data and then choosing an equation of motion into which to substitute the given values (with scant regard to sign conventions). As seen in the examples of work shown, several students did not even first list the data, but began straight away with equations, with the result that they frequently made substitution errors (e.g. entering the initial velocity value in the place of the final velocity).

2. At what speed does the yellow "jumper" leave the table if it is in the air for 1 s?
 [This question was accompanied by a demonstration.]

$$V = u + at$$

$$V = 0 + (-10 \text{ m s}^{-2}) (1 \text{ s})$$

$$V = -10 \text{ m s}^{-1}$$

(in the opposite direction to the table)

Figure 11. Example of a student's response to Question 2 of the diagnostic kinematics test. No sketch is evident and the student begins straight away with a formula. Initial and final velocity symbols are confused with each other and incorrect values are entered. The negative sign entered for the acceleration due to gravity (rounded to 10 m/s^2) causes a negative answer which the student (in the absence of a diagram) is unable to interpret intelligibly.

3. A man on the edge of a building 50 m above street level shoots a bullet straight up into the air at 45 m/s. How long after he fires the gun does the bullet land in the street?



$$v^2 = u^2 + 2gs$$

$$= (45)^2 + 2(10)(50)$$

$$v = 55 \text{ m/s}$$

$$v = u + gt$$

$$55 = 45 + 10t$$

$$\frac{100}{10} = 10t$$

$$t = 10 \text{ s}$$

Figure 12. Example of a student's response to Question 3 of the diagnostic kinematics test. In the absence of any form of sketch or physics diagram, the student repeatedly errs in assigning signs to vector quantities which lie in opposite directions.

3. A man on the edge of a building 50 m above street level shoots a bullet straight up into the air at 45 m/s. How long after he fires the gun does the bullet land in the street?

$$\begin{aligned}
 s &= \frac{v^2 - u^2}{2g} \\
 &= \frac{45^2 - 0^2}{2(10)} \\
 &= \frac{45^2}{20} \\
 &= 101, 25 \text{ m}
 \end{aligned}$$

Figure 13. A second example of a student's response to Question 3 of the diagnostic kinematics test. Besides using incorrect signs and values, the student is uncertain about what has to be determined, and has confused the question's "how long?" (in the sense of time) with "how long?" in the sense of distance.

Figure 14 shows an analysis of the results of the test. For each of the four questions the separate categories indicate the percentage of students who:

- drew any form of rough diagram (**Sketch**);
- used proper physics diagrams including such formalisms as x - and y -axes, sign conventions for direction, etc. (**Physics diagrams**);
- began their calculations with a formally stated mathematical equation (**Formula**);
- obtained the correct answer (**Correct answer**).

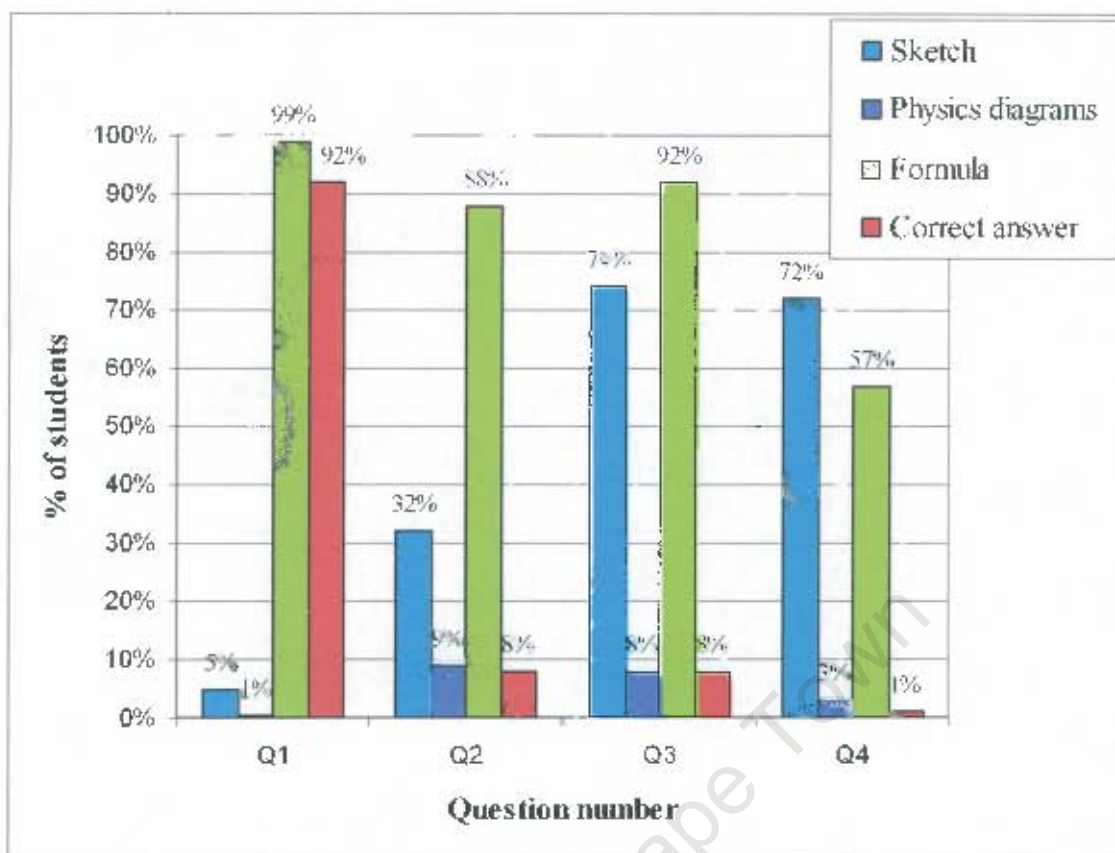


Figure 14. An analysis of the diagnostic kinematics test (2002) showing the percentages of students who variously drew sketches, used formal physics schemata, and used mathematical formulae. The percentage of students who obtained the correct answer is also indicated.

The use of formulae was prevalent throughout the test and declined in Question 4 only because a large number of students failed to reach, or attempt this question. In contrast, sketches appeared in large numbers only once students began to experience difficulties with interpreting the questions. Most of these sketches lacked physics formalism, however, and as a result students were unable to map from their pictures to appropriate mathematical representations. Consequently very few students were able to get the correct answers for Questions 2, 3 and 4. Except in the easy first question, there is a correspondence between the percentage of students drawing formal physics diagrams and the percentage obtaining the correct answer.

As a result of their inappropriate mathematical approaches, most students performed poorly overall in the test (**Figure 15**). Only 27 of the 182 students who wrote passed the test with a score of 50% or more.

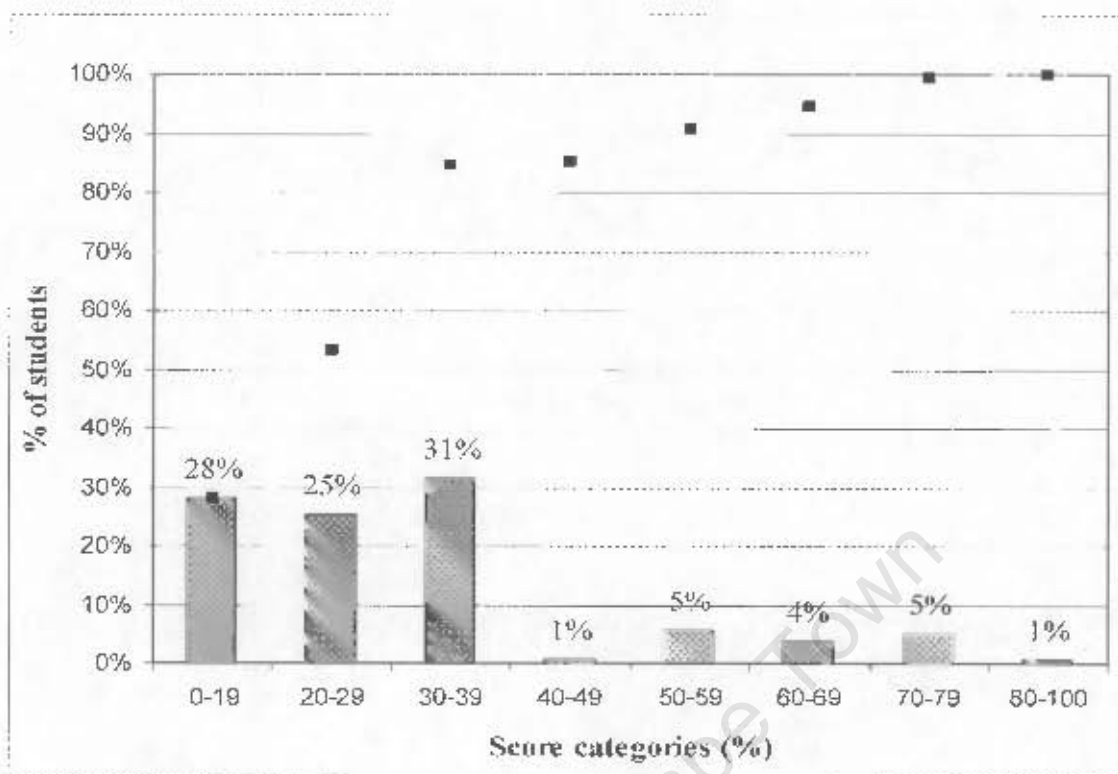


Figure 15. Percentage distribution of 2002 Physics 1 students' scores in the diagnostic kinematics test.

3.3 Summary of benchmarking

To summarise, most students enrolled for Physics 1 at the Cape Technikon have only Standard Grade Physical Science backgrounds and only a few achieved better than a C symbol in the Senior Certificate (Grade 12) examination in this subject. Even fewer achieved A and B symbols on the Higher Grade. Broadly speaking then, the bulk of the Physics 1 classes at the Cape Technikon have poor physics backgrounds.

Furthermore, the results of the numeracy benchmarking studies show that the large majority of these students have very poor mathematical skills. In particular, they experience considerable difficulties with the manipulation of formulae and the application of these in everyday physical contexts, such as those which generally constitute the basis for physics problems. Nevertheless, the predominance of

formulae in the diagnostic kinematics test indicates that these students are very reliant on mathematical methods.

Finally, according to the results of the Classroom Test of Scientific Reasoning, very few Cape Technikon Physics I students are yet operating at a level of scientific reasoning which would facilitate their assimilation of abstract, theoretical tertiary material, especially material presented verbally in the form of traditional lectures and written texts.

University of Cape Town

4. The teaching intervention

All the results from the foregoing benchmarking studies indicated that the Cape Technikon Physics 1 students were under-prepared for *traditional* tertiary physics education and were unlikely to succeed with their existing portfolio of problem solving strategies. In the light of this, there was a strong need to adapt the Physics 1 instruction methods in order to specifically address the shortcomings of the current intakes.

Several alternatives suggested by recent physics education research were considered.

4.1 The case for a “conceptual physics” course

Since mathematics appeared to be one of the central causes of students’ difficulties in physics and their consequent negative attitudes towards the subject, the option of adopting a largely conceptual approach to physics (Hewitt 2002) was considered. As Hewitt argues, “when the focus of a course is learning the techniques of solving algebraic problems, the allure of physics is degraded” (2002, p. xx).

Hewitt’s so-called “conceptual physics” shifts the emphasis towards a qualitative, conceptual understanding of physics by doing away with much of the traditional quantitative manipulation of mathematical formulae. Equations, where they do appear, are regarded initially simply as “guides to thinking” (Hewitt 2002, p. xvii), with the understanding that once students have developed a “sense” of physics (and an

affinity for it) they can go on to develop more formal mathematical processes in second- and third-year physics courses.

This approach, however, was deemed to be inappropriate for the Cape Technikon Physics 1 course for two main reasons. Firstly, one of the explicit objectives of Physics 1, as required by the various diploma programmes in the Faculty of Applied Sciences, is that at the end of the single semester course students should be able to apply certain laws, principles, concepts and formulae *in the solution of numerical problems*. As there is no further physics beyond Physics 1, the mathematical processes must be developed at this level, and, as Linder & Hillhouse (1996) point out “to try and do both [conceptual and mathematical approaches] in the kind of time that is available for such courses would seem to be impossible” (p. 337).

Secondly, students on a conceptual course are evaluated according to their verbal and written communication skills. Given the number of second- and third-language speakers, and the generally poor language abilities of the majority of the Physics 1 students, it seemed unlikely that this intervention would ameliorate students’ attitudes towards physics and improve their chances of dealing successfully with the course.

4.2 Multi-representational problem solving

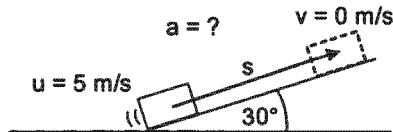
The teaching intervention chosen for this particular study was based on the “multiple representation” strategies devised by, amongst others, Robert Dufresne, William Leonard and William Gerace of the University of Massachusetts (Dufresne *et al.* 1993) and Alan van Heuvelen of Ohio State University (Van Heuvelen 1991b) for helping students develop robust problem solving techniques.

Multiple representation involves sequentially translating a given physics problem from one symbolic “language” to another, beginning (typically) with the (written) verbal description of the problem, moving through increasingly sophisticated pictorial and diagrammatic representations, and ending (usually) with mathematical statements – which can then be used to determine the answer numerically (Figure 16).

(a) **Verbal representation**

A block of mass 250 g is sliding up a slope which makes an angle of 30° with the horizontal. At the bottom of the slope the block is initially moving at 5 m/s. How far along the slope will the block slide before coming to rest, if it experiences a constant frictional force of 0.3 N while it is moving?

(b) **Pictorial representation**



(c) **Physical representation**



(d) **Mathematical representation**

$$v^2 = u^2 + 2as$$

$$0 - (5)^2 + 2as$$

...

Along the x-axis:

$$\Sigma F = ma$$

$$\therefore ma = -F - mg \sin 30^\circ$$

...

Figure 16. Multiple representation: Sequentially translating a given problem from words (verbal representation) into pictorial and diagrammatic representations facilitates a conceptual understanding of the problem and hence results in a more intelligent use of mathematical formulae.

The need for such a structured approach generally arises from students' conservatism in adhering to previously successful, but primitive and stunting problem solving procedures (Buffler & Allie 1993). To address this lack of procedural knowledge on the part of their students, teachers and lecturers traditionally attempt to "teach" physics by presenting a series of worked solutions to given problems. However, a published solution – which typically *begins* with the appropriate equation – "may reveal little about the underlying thought processes that generated it" (Reif 1986, p. 51).

Despite the fact that it has been shown that “in physics, explicit instruction on strategies used by experts improves beginners’ ability to solve problems” (Kurfiss 1988, p. 41), Van Heuvelen points out that the emphasis in most physics courses is still “often on conceptual knowledge and not on the problem-solving procedures themselves” (1990, p. ii), and “there is very little explicit instruction and practice with individual skills such as constructing pictorial representations, free-body diagrams, motion diagrams, and changing a free-body diagram to Newton’s second law in component form” (1991a, p. 893).

By way of excuse, Fuller suggests that the reason for this lack of explicit instruction might be that “many of us have been solving physics problems for so long that we have not recently thought systematically about the problem solving demands of the questions we tackle or those that we ask others” (1982, p. 45). In Kurfiss’ cognitive process model “practice enables declarative knowledge about the procedure to become procedural knowledge mediated by verbal self-instructions, which gradually fade as the procedure becomes more automated. This model helps to understand why experts often have difficulty verbalizing their procedural knowledge – and may not even be aware they are using it” (1988, p. 42).

Even in cases where students are indeed told that diagrams are “useful”, the exhortation to “draw pictures” is seldom accompanied by any metacognitive communication of the pedagogical value of such procedure, “with the result that many students regard diagrams and conceptual reasoning as incidental to the problem solving process” (Buffler & Allie 1993). When diagrams count for marks, some students may simply draw them in *post hoc*, following a traditional mathematical exposition. Furthermore, Dufresne *et al.* refute the idea that mere physical demonstrations and laboratories are innately useful in promoting multi-representational thinking since “students’ representations are not well-connected to the real world” (1993, p. 17).

As a result, despite the fact that back-of-the-envelope sketches are the hallmark of expert problem solvers, very few tertiary level students use pictorial strategies. “Only about 10% of students in conventionally taught precalculus introductory physics

courses and 20% in engineering physics courses use diagrams to help solve problems on final exams” (Van Heuvelen 1991a, p. 892). And as a result of underestimating “the importance or value of representational knowledge ... they rely much too heavily on the algebraic (i.e. symbolic) representation” (Dufresne *et al.* 1993, p. 17).

There are several negative consequences of an over-dependence on a formula-centred approach. Firstly, as already noted, students are often inept at it: “Students generally apply inappropriate equations, and often get the wrong answer” (Dufresne *et al.* 1992, p. 94). They confuse symbols in formulae (e.g. Q for charge with ΔQ for heat) and will either omit critical information (for example when initial speed is *not* zero), or substitute numbers into inappropriate places simply so they can use all the given data, whether it is relevant or not. This repeated, frustrating and usually unexplained failure of the only approach they know often lies at the root of the resentment students feel towards physics, especially once they move on to more complex contexts which no longer lend themselves to the known algorithms.

But it is precisely these complex contexts which provide suitable opportunity and incentive for growth. Unless students are challenged by the difficult demands of context-rich problems (Heller & Hollabaugh 1992) and case study (OCS) problems (Van Heuvelen 1990), they are unlikely to abandon the novice strategies with which they can cope in simple contexts (Heller *et al.* 1992). Only through *repeated* exposure to the same concept in several different complex contexts are students likely to develop a deeper conceptual understanding of physics as opposed to a purely pragmatic series of algorithmic strategies (Van Heuvelen 2001).

A second drawback of the formula-centred approach is that it has been shown to actively militate against the promotion of conceptual understanding. “The equations become crutches that short-circuit attempts at understanding” (Van Heuvelen 1991a, p. 893). A lack of understanding perpetuates the “disconnected and amorphous knowledge structure” characteristic of novice problem solvers (Gerace 2001), instead of helping them consolidate or “chunk” their knowledge base by providing “opportunities for students to see that a small number of concepts are the basis for many diverse applications” (Van Heuvelen 1991a).

As Fuller states: “Every physicist knows the importance of having the correct concept in mind before beginning to solve a problem” (Fuller 1982, p. 43), while Reif quotes Hans Bethe as saying “From Fermi I learned ... to look at things qualitatively first and understand the problem physically before putting a lot of formulas on paper” (Reif 1995, p. 23). Qualitative clarity for the inimitably colourful Richard Feynman apparently involved “a half-assedly thought-out pictorial semi-vision thing” (Reif 1995, p. 23).

The value of the multi-representational approach therefore lies in the opportunities it presents to students to develop their conceptual understanding of the physics which lies behind a given problem before they rush thoughtlessly, aimlessly (and often anxiously) into a “plug and chug” activity. “Translating from one representation to another increases their ability to use unfamiliar representations and leads to a richer understanding of concepts” (Dufresne *et al.* 1993, p. 17). Without such an understanding, students are usually unable to generalise the solution to one problem to others of the same type. The student complaint recorded by Heller & Heller (1999, p. 5): “I can follow the example problems in the text, but your test problems are too different” was frequently heard in Cape Technikon Physics 1 classes prior to 2002.

Reif (1995) justifies the requisite *explicitness* of training in the pre-mathematical steps of problem solving by arguing that “skills of description and interpretation are sufficiently complex that they deserve to be taught in their own right *before* students are asked to use them in more demanding problems” (p. 23).

Pictorial representations assist students in several different ways. Firstly, according to Van Heuvelen (2001), “the human mind relates best to picture-like representations that emphasize qualitative features but not detailed precise information” (p. 1141). By linking words to what linguists call “referents” – for example, visual icons such as the arrows in motion diagrams (**Figure 16**) – beginning students develop a better understanding of abstract concepts such as velocity and acceleration.

Furthermore, there is evidence to suggest that modern generations are becoming *increasingly* reliant on visual information, as students brought up on a concentrated visual diet of television and electronic games tend to favour right-brain processes (Alesandrini 1981). As the practices of reading and oral storytelling wane, students are increasingly neglecting the left cerebral cortex skills required for processing language, both aural and written. To such visually oriented students, pictures offer a concrete, more accessible route in to the concepts which lie behind a given problem, by summarising “the prominent features of a process while removing the noisy details that distract from understanding” (Van Heuvelen 1991a, p. 891).

Secondly, pictorial representations facilitate the subsequent strategising process, helping students choose between several possible conceptual approaches to the problem. “A good initial analysis of a problem can greatly facilitate the task of finding its solution” (Reif 1995, p. 26). This strategising activity, in turn, promotes the development of expert problem solving behaviour since, “by considering alternative solution paths, new strategic knowledge elements will be developed and prioritized as concepts are clustered around those principles that are found to be useful for problem solving” (Buffler & Allie 1993).

Finally, the diagrams allow students to check their final solutions for completeness and consistency by considering questions such as: Have I included the direction in my answer? Does the direction of the resultant force agree with the direction of the acceleration? Is the magnitude of the answer reasonable in the context of the drawing’s account of reality?

Because of its proven success in improving student performance in physics, the multi-representational problem solving approach is growing in popularity and usage world-wide. To date, however, most studies done on this approach appear to have concentrated on measuring academic outcomes such as improved marks on the Force Concept Inventory and other benchmarking instruments. The researcher is unaware of any studies specifically relating multi-representational problem solving development with more affective outcomes such as students’ attitudes towards and their own beliefs about learning physics.

4.3 Multi-representational problem solving in practice at the Cape Technikon

In 2002 Cape Technikon Physics 1 students were given explicit instruction in multi-representational physics problem solving for the first time.

The intervention was introduced by administering the diagnostic kinematics test described in 3.1.3. After the marked scripts had been returned, students were shown how each of the problems (including the complex ones) could be elucidated and then relatively easily solved using the principles of multi-representational problem solving.

Students were then each given a single-page, quick-reference document (*An approach to solving physics problems*, Figure 17) detailing four specific, sequential steps they should follow when solving problems. The document is a modified version of that produced by the University of Cape Town Physics Education Group (Buffler & Allie 1993) which is turn based on the Describe, Plan, Implement, Check scheme described originally by Reif *et al.* (1976) and further refined by Heller *et al.* (1992). A schematic representation of the process stages and the inter-relatedness of the particular types of knowledge and knowledge structures required for each step (Dufresne *et al.* 1993) are shown in Figure 18 (based on Buffler & Allie 1993).

AN APPROACH TO SOLVING PHYSICS PROBLEMS

(Adapted from a UCT PHYSICS EDUCATION GROUP document.)

STEP 1 FOCUS ON THE PROBLEM AND REPRESENT IT PICTORIALLY.

- Construct a **mental image** of the problem – do your friends have the same image?
- Draw one or more **pictures** which show all the important objects, their motion and any interactions.
- Now ask, “**What is being asked?**” “Do I need to calculate something?”
- Think about what **concepts** and **principles** you think will be useful in solving the problem and when they will be most useful.
- Specify any **approximations** or simplifications which you think will make the problem solution easier, but will not affect the result significantly.

STEP 2 DESCRIBE THE PHYSICS WITH A PHYSICAL REPRESENTATION.

- Draw a **coordinate axis** (or a pair of axes) onto your picture above (deciding carefully where to put the origin).
- Translate your pictures into one or more **physics diagrams** (with axes) containing only the information needed for a mathematical solution.
 - If you are using kinematics concepts, draw a *motion map* specifying the object's velocity and acceleration at definite positions and times.
 - If interactions or statics are important, draw *free body (force) diagrams*. When using conservation principles, draw “before” and “after” diagrams to show how the system changes.
 - For circuit problems draw a *circuit diagram*.
 - For optics problems draw a *ray diagram*.
- Define a **symbol** for every important physics variable in your diagram and include any numerical information you have in the label (e.g.: $T_1 = 30 \text{ N}$).
- Identify your **target** variable (“What unknown must I calculate?”). Indicate it on your diagram with a question mark. (e.g.: $T_2 = ?$).

STEP 3 REPRESENT THE PROBLEM MATHEMATICALLY AND SOLVE.

- Only now choose a **mathematical equation** (formula) which relates the physics variables in your diagram to each other. (Very occasionally you may need to combine two or more equations into one formula.)
- **Substitute** the values (numbers with units) into *this* formula (ie do NOT first change the subject of the formula!)
- Make sure you are using only **standard SI units**.
- **Calculate** the numerical **result** for the target variable.

STEP 4 EVALUATE YOUR SOLUTION.

- Do **vector quantities** have both magnitude and direction?
- Does the **sign** of your answer make sense? Have you **interpreted** a negative sign?
- Can someone else follow your solution? Is it **clear** (and easily visible)?
- Is the result **reasonable** and within your experience?
- Have you given the **units**, and do they make sense?

Have you answered the question?!

Figure 17. The ready-reference document supplied to students at the beginning of the intervention to continually remind them of the four specific, sequential steps to be followed when solving problems.

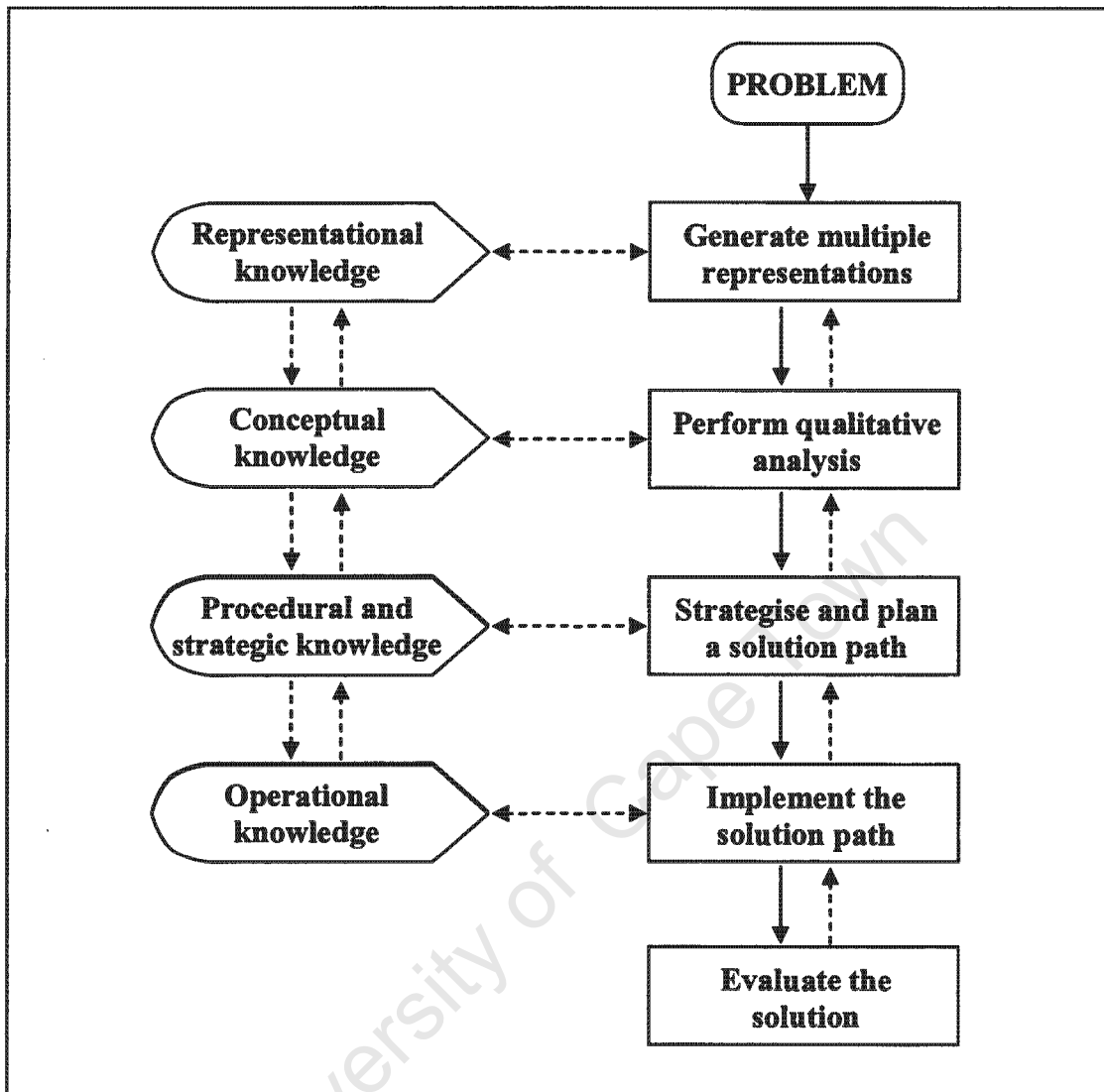


Figure 18. Stages of multi-representational problem solving and the type of knowledge required for each stage.

Each of the problem solving steps was explained (and justified) to the students, before the full four-step process was applied to each of the four diagnostic test questions in turn by the lecturer using the chalkboard.

Because these were the innovative (and unfamiliar) parts of the process, particular attention was paid to coaching students in the first two steps of the process. They were shown how pictorial and graphic physics information could help them “stand back” from the problem in order to gain an important overview. They were then taught how to strategise at this stage, using the (pictorial) data array to decide on the

underlying *concept* (not simply a mathematical formula). Students were shown that once the concept was clear it was relatively easy to decide on the appropriate formula and start down the final solution path.

After the holistic modelling on the diagnostic test questions, students were given further specific instruction in using various pictorial representations of kinematics quantities, for example, using vector arrows of appropriate size and direction to represent velocity and acceleration. To reinforce this instruction they were then given structured worksheets on which to work both individually and in small groups (Motion maps, Appendix E). The worksheets were based largely on the Active Learning Problem Sheets and Overview, Case Study (OCS) Physics material developed by Alan van Heuvelen (1991a) and Materials for Developing Concept-Based Problem-Solving Skills in Physics (Gerace *et al.* 1992).

Throughout the remainder of the semester the pre-mathematical, conceptual steps of problem solving were continually reinforced through explicitly highlighting the multi-representational approach in class, introducing compulsory tutorials (in 2003) and various other incentives. In tests, marks were awarded for pre-mathematical work, with some questions requiring *only* the pictorial and physics representation stages.

Five educational strategies were implemented to reinforce the underlying message of “conceptual understanding before mathematical manipulation”.

4.4 Educational strategies used to reinforce the intervention

The Physics 1 course consisted of several different components, most of which were specially adapted to reinforce the new multi-representational problem solving intervention. Table 5 shows a summary of the different instructional components used during 2002 and 2003, each of which is described in greater detail below. (As

mentioned earlier, the laboratory component was run independently and did form part of this study.)

Table 5. Summary of instructional components of the Physics 1 course.

Component	Activities	Hrs/wk	Staff	Compulsory?
Lectures	<ul style="list-style-type: none"> • Reading quizzes • Formal instruction • Demonstrations • Class discussion • ConcepTests • 1 min papers 	4½	Lecturer	Y
Tutorials	<ul style="list-style-type: none"> • WPS: small group discussion & strategising of problems 	1½	Lecturer Course tutor	Y
Morning tutorials	<ul style="list-style-type: none"> • Problem solving in small groups 	1	Peer tutors	N
Walk-in consultation	<ul style="list-style-type: none"> • One-on-one assistance • Counselling 	1-2 1-7	Lecturer Course tutor	N
Laboratories	<ul style="list-style-type: none"> • Practical work 	1½	Lecturer Lab assistant	Y

4.4.1. Active, cooperative learning during lectures

A feature of Physics 1 classes (even prior to 2002) was the extent to which formal theoretical contact time (so-called lectures) avoided the traditional “chalk and talk” method of information transfer (a method in which “the transmission is efficient but the reception is almost negligible” (Van Heuvelen 1991a, p. 895)), and instead involved active, cooperative learning on the part of students.

Early in the semester students were given formal instruction in effective group work; how to listen attentively and critically; even how to sit (the gently tiered lecture

theatres with rotating seats allowed groups consisting of two pairs of students to sit facing each other). Since “most students come from a school background which has discouraged any notion that fellow students have anything useful to contribute to one’s learning” (Buffler & Allie 1993) it was usually also necessary to spend some time at the outset on a well-motivated rationale, and to follow this up with continual positive feedback to show the effectiveness of the activity.

One of the key objectives of cooperative group work in physics is to correct the common misconception among students that learning physics is a passive activity in which the emphasis lies on “the lower-order thinking skills of recall and comprehension, rather than the higher-order skills of analysis, synthesis and evaluation” (Heller & Heller 1999, p. 4). By actively participating in class and interrelating with their peers, students adapt more readily to the tertiary environment and also develop important subsidiary attributes such as communication and teamwork skills. “Students’ talking and listening enhances their learning and hopefully improves their communications skills” (Van Heuvelen 2001, p.16).

In discussing problems with each other, students are compelled to confront and deal with their own (and others’) misconceptions, learning at the same time to use the “language of physics”, thinking and talking like physicists. In this way, the process of arguing with others, or *teaching* them, becomes the best way of *learning*. “Broadly speaking, what distinguishes the man who knows from the ignorant man is an ability to teach” (Aristotle).

Critically for this study, Heller *et al.* (1994) found cooperative group work essential for forcing students to abandon their “plug and chug” methods in favour of a structured problem solving strategy. They observed that students otherwise reverted to old methods, both if the problem was simple (the old method worked well enough) or more complex (unfamiliarity with the new method led to failure, which in turn led to regression). After an initial period where students had to overcome their shyness and reluctance to appear ignorant in front of their peers, the cooperative environment fostered experimentation with and mastery of the new, structured strategy. Since groups were generally more successful than individuals at solving complex problems,

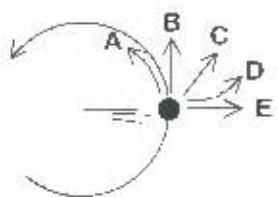
students were more easily convinced of the efficacy of the new method, and more willing to adopt it.

4.4.2. ConcepTests©

Group work activities based on carefully selected multiple choice questions known as “ConcepTests” (Mazur 1997), which had proved to be especially successful both in promoting group interdependence and in focussing students’ attention on underlying physics concepts, were used extensively in 2002 and 2003.

ConcepTesting involves posing students single multiple choice questions based on specific physics concepts such as Newton’s laws of motion, Archimedes’ principle, etc. (Figure 19).

The sketch is a top view of a stone being swung around in a horizontal circle at the end of a piece of string. If the string breaks at the instant shown, along which path will the stone continue?



A boat floats in a dam. It has a large rock for an anchor. When the rock is thrown overboard and sinks to the bottom of the dam, the level of the dam

A drops
B remains the same
C rises

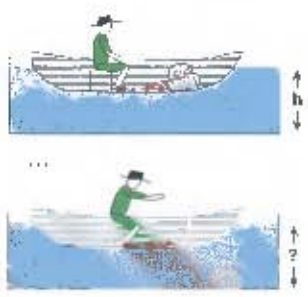


Figure 19. Examples of multiple choice questions used as ConcepTests.

After first considering the question on their own for about a minute, students indicate their choices with a show of hands or coloured cards (to provide feedback for the lecturer), before discussing and justifying their answers with their peers in informal

groups of three or four for another two or three minutes. During this latter time the lecturer moves between groups, monitoring student participation and facilitating discussion. A final “vote” allows the lecture to monitor students’ progress towards the correct conceptual thinking and to decide whether further instruction and testing are necessary.

Besides reinforcing the importance of collaborative effort and conceptual understanding (very few of the questions involve any form of calculation), ConcepTests provide an excellent forum for exploring students’ conceptions. Most of the questions are deliberately designed in such a way that many students are initially “trapped” by their preconceptions into selecting one or more of the incorrect choices. Then, during the discussion with other students (and sometimes a follow-up demonstration), in a process known as cognitive conflict, students are compelled to confront the inconsistencies and errors in their preconceived ideas. Misconceptions are notoriously persistent, so only after they have seen their own reasoning fail (repeatedly) are students (sometimes) ready to relinquish their incorrect ideas and adopt scientifically more rigorous and consistent viewpoints. As Fuller states: “the time when we are most likely to develop new understandings and new strategies is when our present experiences do not fit our mental preconceptions. This period of disequilibrium, of being slightly confused, is the time when we are most likely to make intellectual growth” (1982, p. 47).

It is essential to spend time addressing students’ misconceptions in each section of physics before they are given further training and drill in numerical problem solving. “Instruction must ensure that students can adequately interpret any concept or principle *before* they are asked to use it to perform more demanding problem-solving tasks” (Reif 1995, p. 20).

ConcepTests play an important role in developing this pre-requisite conceptual competency. Without a clear understanding of the concepts involved in a question it is impossible to produce correct physics’ diagrams; without the correct and complete diagrams students fall back on their hit-and-miss mathematical approaches. It is also difficult to assess the validity of a numerical solution without some understanding of

the concepts underlying the problem. Finally, the immediate feedback supplied by the voting system allows the lecturer to time carefully the introduction of more complex, context-rich problems, i.e. those which will oblige students to implement and practise multi-representational strategies.

4.4.3. Weekly Problem Sets

Physics 1 students were given a weekly set of four compulsory problems in order to enforce regular, repetitive practice of the correct multi-representational problem solving techniques and, at the same time, to provide the lecturer with continual feedback on students' progress and possible problem areas.

Each Weekly Problem Set (WPS) was given out in a contact period during which students were first given general feedback about the previous WPS, and possible further corrective instruction. Individual scripts were returned, sometimes with written comments and corrections. Students then broke up into groups of three or four to address the next set of questions, focussing on the initial problem solving stages of analysis and multi-representational translations. During this time the lecturer and an assistant moved between groups, facilitating both the group work and the initial set-up of problems and the appropriate pictorial representations.

Following the WPS contact session, students were typically given three to four days in which to complete the problem set before submitting it for marking. They were therefore able to consult with each other and the course tutor, or the lecturer, although the submitted answers were supposed to be each student's own work.

As in tests, marks were awarded for the initial multi-representational stages of problems, and some questions did not require students to go beyond this stage. To stress the importance of the exercise, WPS marks counted towards students' year marks. (In all, the 12 Weekly Problem Sets in 2003 counted about 8% of each student's total mark for the course.)

4.4.4. Course tutor/mentor

The full WPS roll-out in 2003 was made possible by the appointment of a qualified course tutor/mentor with previous experience in developing first year physics students' problem solving abilities. Given the size of the Physics 1 group in 2003 (287 students), the amount of weekly marking and correction required to provide adequate feedback to both students and lecturer would have been too onerous for the lecturer. Students were also able to consult with the tutor/mentor during office hours in order to gain further assistance and guidance.

4.4.5. Peer tutors

In addition to the course tutor/mentor, three second year students who had previously undergone two days of training with the Cape Technikon's Student Tutor Services unit ran half hour tutorial sessions before the start of formal lectures on two mornings of the week. During these voluntary sessions the tutors assisted students with problems from the current Weekly Problem Set, exercises in the course notes, and additional examples devised by the tutors themselves. Other smaller sessions were sometimes arranged privately.

Peer tutors are specifically trained not simply to provide answers, but to assist students in their own attempts at mastering the work and to facilitate group discussions. They do not, however, receive specific subject training beyond what they themselves learnt in Physics 1 (usually the previous year, and sometimes with only moderately good results). Since the current, explicit, multi-representational problem solving training was a new feature of Physics 1, peer tutors in 2003 were not yet expected to play a large role in developing students' skills in this particular arena.

5. Evaluating the effectiveness of the new intervention

Several different instruments were used to assess the impact of the multi-representational problem solving intervention on students' attitudes towards learning physics and their subsequent overall academic performance. Several case studies are also presented to illustrate the progress of these students in the course.

5.1 Evaluation instruments

The chief instrument used to measure shifts in students' affects and attitudes was a physics expectations survey conducted both prior to and following the semester physics course.

The lecturer was also able to monitor the extent to which students were altering their beliefs about learning and their problem solving paradigms during the course of instruction with the aid of the Weekly Problem Sets, "one-minute papers" and the formal class tests.

Finally, the overall impact of the new teaching intervention was assessed using course evaluation surveys and the results of the final three-hour Physics 1 examination.

5.1.1. Physics expectations surveys

Pointing out that “students’ epistemologies play an important role in helping them construct knowledge”, David May and Eugenia Etkina (2002) encourage the measurement and study of epistemological beliefs because of the extent to which these impact on student motivation and their selection of learning strategies. “In particular, immature beliefs affect students’ ability to integrate their understanding of science concepts” (p. 1249).

A version of the Maryland Physics Expectations (MPEX) Survey (Redish *et al.* 1998) was adapted slightly for the South African context. The modified version, referred to here as the physics expectations survey, or simply the expectations survey (Appendix C), was administered to all Physics 1 students in 2002 and 2003, both before and after 15 weeks of instruction in the new multi-representational strategies for physics problem solving, in order to measure values and monitor shifts in students’ beliefs about learning physics. As in the case of the test of scientific reasoning described in Section 3.1.2, the physics expectations survey was designed specifically to overcome the problems associated with eliciting attitudinal data from large classes where the traditional process of conducting interviews is logistically impractical.

The survey (a Likert-scale – agree-disagree – questionnaire) was developed by the physics education research group at the University of Maryland to measure (*inter alia*) the differences between students’ and experts’ beliefs and cognitive expectations about tertiary physics, and also the extent to which students’ initial beliefs can be altered by instruction (Redish *et al.* 1998). It has been validated through interviews with students and subsequent application to a great number of student groupings around the world.

The survey helps to rank students on a spectrum ranging from a “binary stage” (where students expect to learn by simply being given all the right answers by the lecturer, for example) to a “constructivist stage” (where students accept responsibility for constructing their own meaning from the information made available to them) (Redish *et al.* 1998). According to Redish, “students who want to become creative scientists

will have to move from the binary to the constructivist stage” (1998, p. 213), but for the purposes of this study, less attention was paid to the characteristics of individual students than to the extent to which the cohort progressed towards adopting a more appropriate standpoint as a result of the teaching intervention.

This shift in students’ beliefs was measured by administering the survey both before and after the semester’s instruction.

The original MPEX survey was modified in order to simplify the language of the questionnaire and replace the category dealing with the amount of personal effort required to make sense of physics with an item specifically referring to beliefs about the value of multi-representational approaches to problem solving. The original 34 items were reduced to 24. The expectations survey used in the present work (Appendix C) thus measures the following six aspects of student beliefs about what is required of them in order to succeed in physics:

1. *Independence* – Do students expect to be taught passively, or are they willing and eager to play an active role in their own learning?
2. *Coherence* – Do students see physics as a coherent whole, where a few general principles apply to a wide variety of phenomena, or as a disjointed collection of facts, concepts and algorithms?
3. *Concepts* – How much importance do students attach to the understanding of concepts prior to mathematical manipulations?
4. *Reality link* – Can students transfer knowledge between the contexts of classroom and everyday life?
5. *Mathematics link* – Do students see mathematics as a language which can inform them about physics, or just as a tool for processing numbers?
6. *Multiple representation* – Do students recognise the value of formulating a problem pictorially in order to gain a clearer conceptual understanding before resorting to numerical manipulations?

The MPEX questionnaire was originally calibrated by Redish *et al.* (1998) by giving it to a number of “experienced physics instructors who have a high concern for educational issues and a high sensitivity to students” (p. 216). These were all teachers “committed to implementing an interactive engagement model of teaching in their classrooms” (p. 217). The responses chosen by these experts *as the answer they would like their students to give* (usually with better than 80% agreement within the group) were designated as the expert, or appropriate responses. A choice made in agreement *with the expert response* (irrespective of whether the response to the actual item is “agree” or “disagree”) is deemed to be “favourable”, while disagreement with the experts constitutes an “unfavourable” response.

In this way the responses of a tested group can be illustrated by means of a “favourable-unfavourable” plot, where the percentage of respondents answering the same way as the experts is plotted against the percentage of those answering unfavourably. Redish refers to such plots as *agree-disagree (A-D) plots*, but as this leads to confusion with the actual Likert-style responses to the items themselves, the term “favourable-unfavourable plot” is preferred in this study.

Each survey item consists of a propositional statement requiring a response on a five-point scale ranging from “strongly disagree” (A) to “strongly agree” (E). For the purposes of scoring, A’s and B’s are counted together, and D’s and E’s are counted together, and each total is converted to a percentage of the number of respondents. The total number of C’s (neutral responses) and blank answers is not recorded directly, but shows up on the plot as the distance between each favourable-unfavourable coordinate pair and the line delimiting the range of possible values (i.e. the diagonal line joining (0; 100) on the Favourable axis and (100; 0) on the Unfavourable axis).

As an example, **Table 6** below shows, for five of the belief categories, as well as overall, the average percentages of the experts giving favourable responses versus those giving unfavourable responses (Redish *et al.* 1998). These data are also shown plotted in **Figure 20**.

Table 6. Average percentages of the experts giving favourable/unfavourable responses in five specific belief categories as well as the overall average percentages for all items in the MPEX survey (Redish et al. 1998).

Independence	Coherence	Concept	Reality link	Maths link	Overall
93/3	85/12	89/6	93/3	92/4	87/6

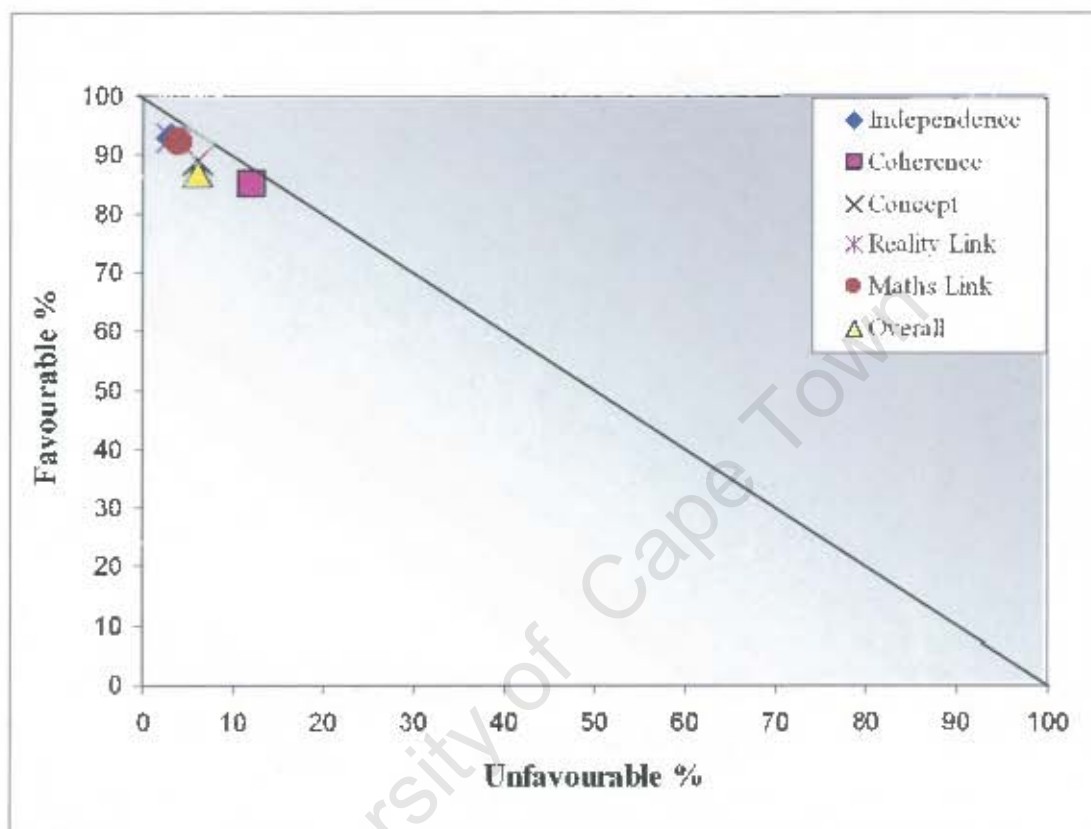


Figure 20. Favourable-unfavourable plot for the experts in five specific belief categories of the MPEX survey as well as the overall average for all items (Redish et al. 1998).

As is to be expected from the expert group, the points all lie high and to the left in the possible triangle of points, and reasonably close to the diagonal (i.e. the experts were generally clear about, and assertive in, their responses).

Published results from surveys conducted at other institutions allowed for comparison of the Cape Technikon group with the (expert) calibration group and other first year student groups (primarily from the United States). A post-instruction form of the survey (which used the same questions as the pre-instruction survey, but a modified answer sheet, Appendix D) was also administered, which allowed the shift in

perceptions amongst the Technikon group to be compared to the shifts achieved with the other first year groups.

5.1.2. Weekly Problem Sets

The Weekly Problem Set programme afforded a regular opportunity for the lecturer to monitor students' adoption of the new multi-representational problem solving strategies and to give students immediate feedback on their progress. Since, however, the questions used in the problem sets were very similar to those set in tests and the final examination, the reporting of student responses to them will be covered in the section on tests and examinations.

5.1.3. Tests and examinations

Students' progress was also monitored by means of three formal one and a half hour class tests during the course of the semester and a final three hour examination at the end of the course.

Each of the class tests and the examination began with a section of multiple choice questions (comprising about a third of the total marks) aimed at testing students' conceptual knowledge. "Long" questions requiring the solving of problems comprised the rest of the question paper. Sometimes the first part of such questions asked for a definition, or the statement of a principle germane to the solution of the problem, in order to help students to focus on the relevant underlying concepts.

To encourage students to adopt the new multi-representational approach towards problem solving and to take cognisance of the fact that "the solution to the problem is the whole series of representations with the value of the unknown quantity being only a small part of the solution" (Van Heuvelen 1991a, p. 892), marks were sometimes specifically allocated for diagrammatic work. In some cases, test or exam instructions stipulated that *only* the pre-mathematical steps were required.

Pre-mathematical stage marks were recorded separately in order to monitor students' multi-representational development and compare it with their overall physics marks. (Since the multi-representational approach was taught specifically only for the Dynamics section of the course, and not in Thermodynamics or Electricity, not *all* tests or examination questions were relevant to the study.)

In many cases the questions used to evaluate students' multi-representational skills were well above the standard normally set for Physics 1 at the Cape Technikon, being higher order, context-rich questions which could not easily be solved by simple "plug and chug" methods (see: question 2.4 of Test 1, Appendix H; question 2.2 of Test 2, Appendix I; questions 2.2.2 and 3.1.1 of the final examination, Appendix J). Students had not previously been challenged by questions of this complexity and difficulty.

5.1.4. Course evaluation questionnaires

Several surveys of student opinion were conducted during the course of the semester, ranging from frequent, informal "one-minute papers" to the modified version of the generic Cape Technikon formal, end-of-course evaluation questionnaire (Appendix F). A specially designed questionnaire (Appendix G) was used to gauge the impact of the Weekly Problem Set program and its concomitant tutors, as well as the cognitive conflict style of teaching used by the lecturer.

5.2 Evaluation results

Data collected from the various evaluation instruments described above are reported below.

5.2.1. Shifts in students' epistemological beliefs about physics

Redish *et al.* (1998) reported on using the MPEX survey to test more than 1 500 students from six different institutions: the University of Maryland, the University of Minnesota, Ohio State University, Dickinson College, an anonymous small public liberal arts college and an anonymous public two year college. The percentage of these students who gave favourable and unfavourable responses for all categories of the survey (in accordance with the answers determined by Redish's panel of expert physics instructors) are shown in Table 7, together with the corresponding percentages of Cape Technikon Physics 1 students surveyed in 2002 (N = 119) and 2003 (N = 163). The data are *matched*, that is, only students who took part in both the pre- and post-instruction surveys have been included.

Table 7. Percentages of students giving favourable and unfavourable responses for all categories of the pre-instruction physics expectations surveys.

		All categories of the expectations survey	
		Favourable	Unfavourable
The present work	Cape Technikon 2003	57%	24%
	Cape Technikon 2002	58%	23%
Reported in Redish <i>et al.</i> 1998	University of Maryland	54%	23%
	University of Minnesota	59%	18%
	Ohio State University	53%	23%
	Dickinson College	61%	15%
	A small public liberal arts college	57%	23%
	A public two year college	55%	22%

The favourable-unfavourable plot of these data (**Figure 21**) illustrates the similarity between the pre-instruction epistemological beliefs and expectations of the Cape Technikon students (in both 2002 and 2003) and their counterparts in the United States in all categories of the survey. The plot also highlights the “substantial discrepancy” noted by Redish *et al.* between the responses of pre-instruction students and those of the experts (1998). Student answers correspond with the expert view only about 55% of the time, and are explicitly at odds with them almost 25% of the time.

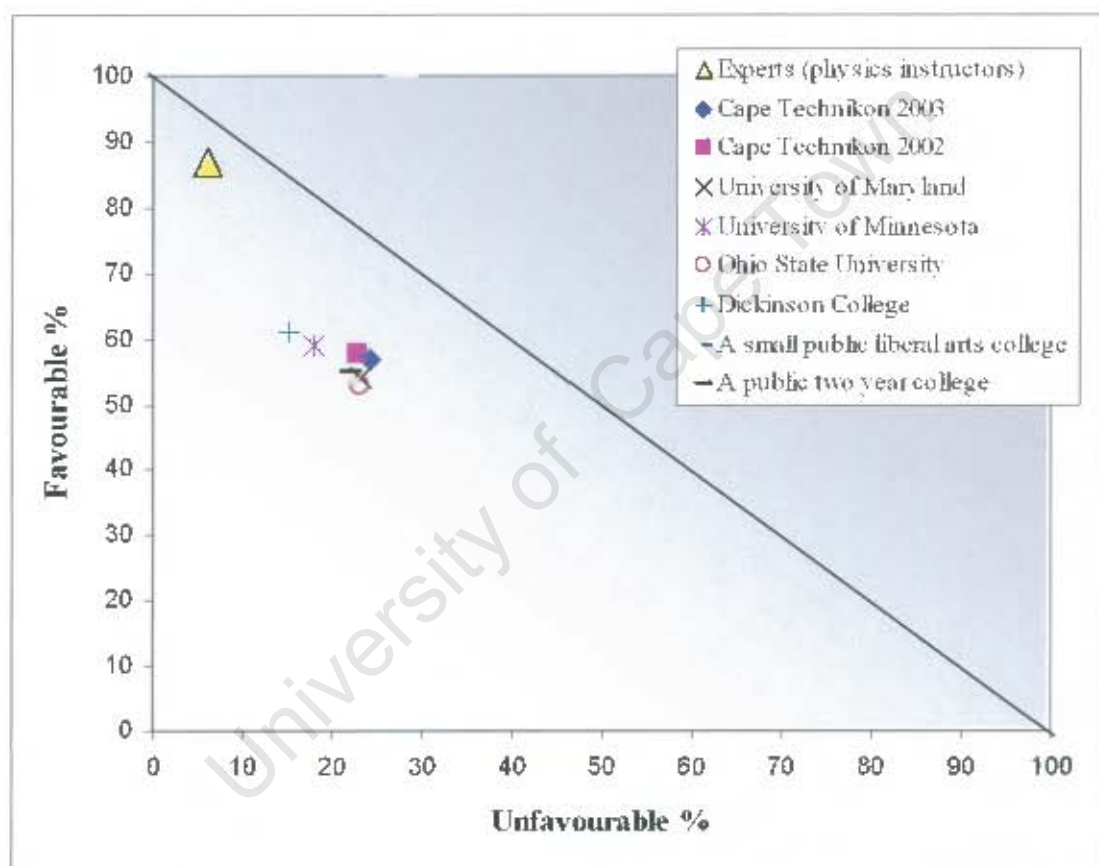


Figure 21. Pre-instruction expectations survey: comparative scores. A favourable-unfavourable plot comparing Cape Technikon students' pre-instruction overall scores for all categories of the physics expectations survey with those of the experts, as well as with those of various United States student groups (Redish *et al.* 1998).

More detailed information about the Cape Technikon students' pre-instruction scores in the six individual categories used in the local expectations survey in 2002 and 2003 is given in **Figure 22**. The plot shows the overall similarity between the pre-instruction beliefs of two year groups.

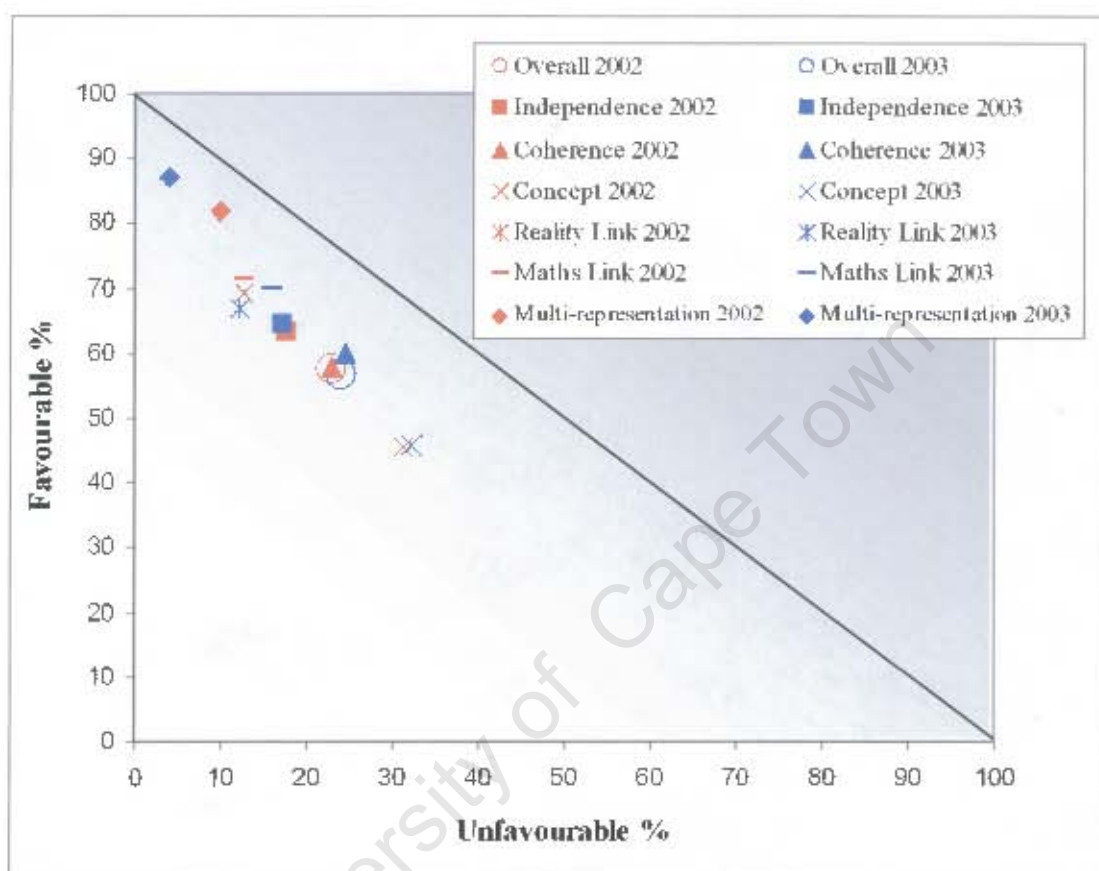


Figure 22. Pre-instruction expectations survey: Cape Technikon details 2002 and 2003. A favourable-unfavourable plot of 2002 and 2003 Cape Technikon students' pre-instruction responses for the six individual categories of the physics expectations survey, as well as their overall scores.

Figure 23 and Figure 24 show, for the 2002 and 2003 Cape Technikon groups respectively, how the students' epistemologies changed from the pre-instruction survey to the post-instruction survey. Besides three individual categories on the 2003 plot (Multi-representation, Coherence and Independence) which show a slight negative shift, all other pre- to post-instruction changes, including the overall shift in physics expectations for both the 2002 and 2003 students, are positive.

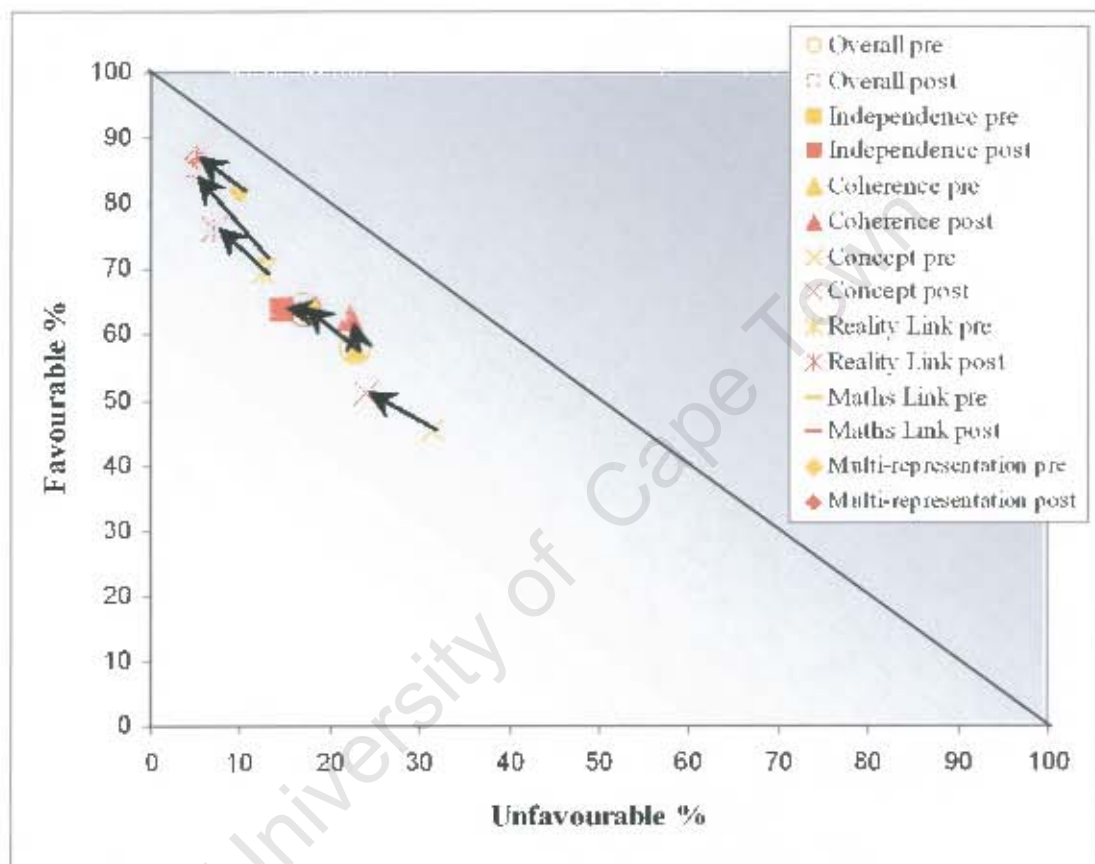


Figure 23. *Physics expectations shifts: Cape Technikon 2002.* A favourable-unfavourable plot of 2002 Cape Technikon students' responses to both the pre- and post-instruction physics expectations surveys, showing the shift in overall average, as well as the shifts for each category of the surveys.

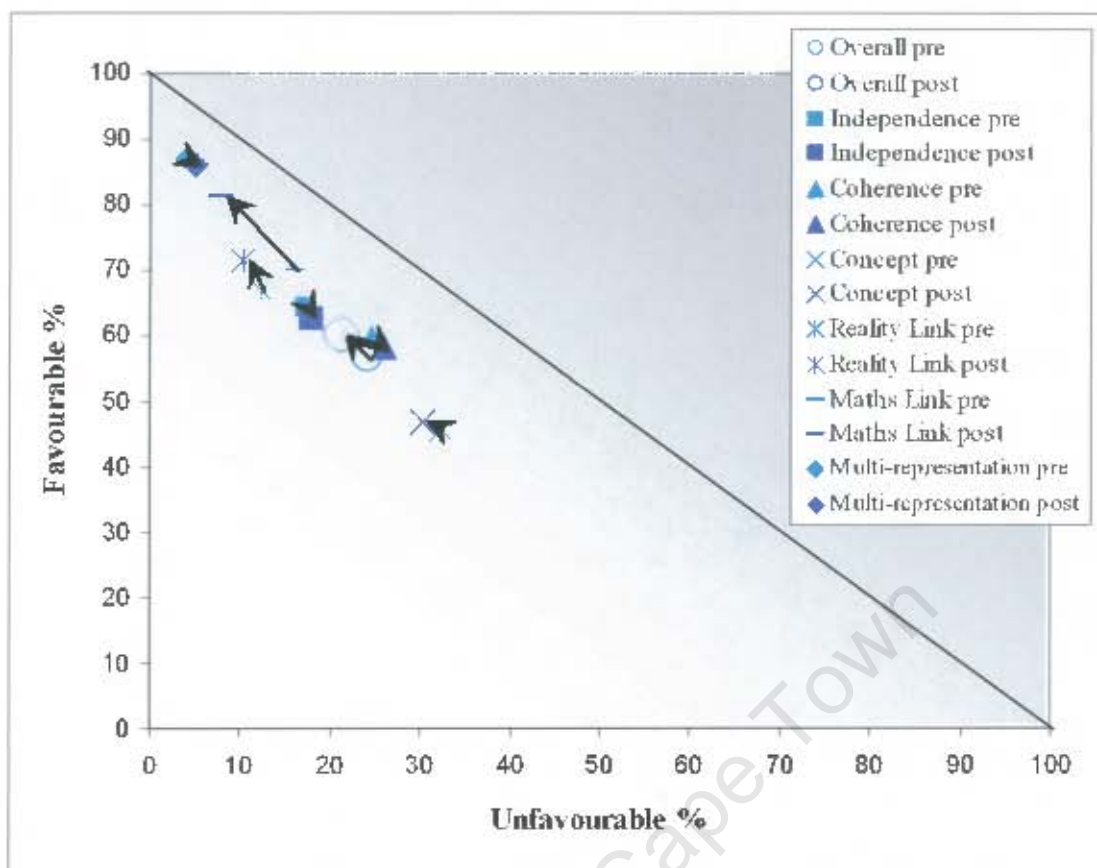


Figure 24. *Physics expectations shifts: Cape Technikon 2003.* A favourable-unfavourable plot of 2003 Cape Technikon students' responses to both the pre- and post-instruction physics expectations surveys, showing the shift in overall average, as well as the shifts for each category of the surveys.

Figure 25 compares the shifts (from pre- to post-instruction) in the overall averages of the Cape Technikon groups with those of each of the six student groups surveyed by Redish *et al.* (1998). To accentuate the comparisons, the diagram shows only the upper left portion of the complete favourable-unfavourable plot. As reported by Redish *et al.* (1998), at every one of the United States institutions studied "the overall results deteriorated as a result of one semester of instruction" (p. 222).

By contrast, the overall results of both the 2002 and the 2003 Cape Technikon groups underwent *positive* shifts following instruction in the new multi-representational problem solving approach to physics.

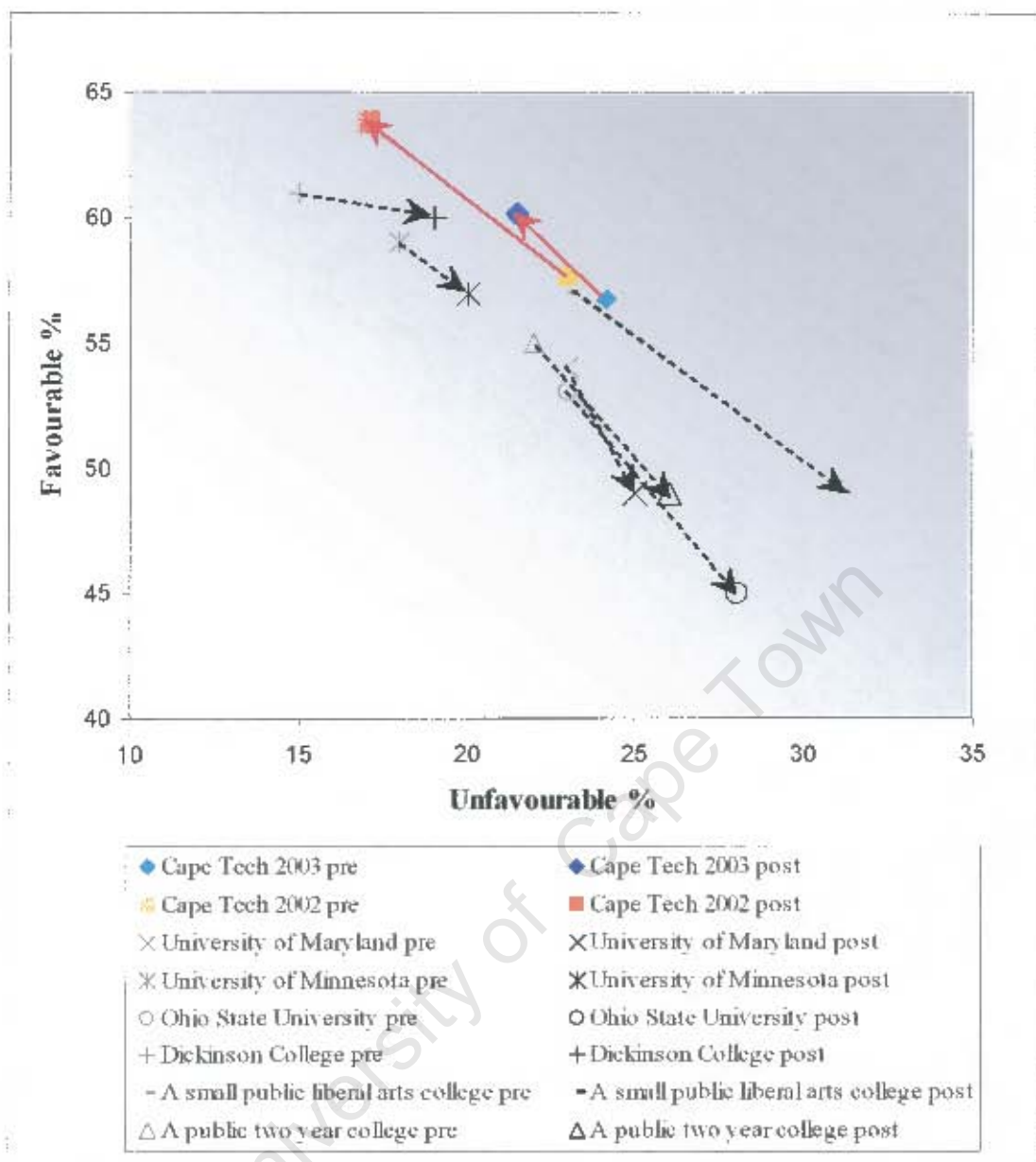


Figure 25. Physics expectations shifts: Comparison between the Cape Technikon and United States groups. An enlarged section of a favourable-unfavourable plot showing the shifts between the pre- and post-instruction scores of the 2002 and 2003 Cape Technikon students and those of the six United States institutions reported by Redish et al. (1998). In contrast to the negative shifts of each of the six United States student groupings, the physics expectations of both the 2002 and the 2003 Cape Technikon student groups improved after a semester of instruction in the new multi-representational approaches to physics problem solving.

5.2.2. Students' use of multi-representational techniques in tests and examinations

Figure 26 compares the first two class tests (Appendices H and I) and the final examination of 2003 (Appendix J) in terms of the number of students who produced formal physics diagrams for the relevant questions, the marks they achieved for those diagrams, and the overall class test or examination average.

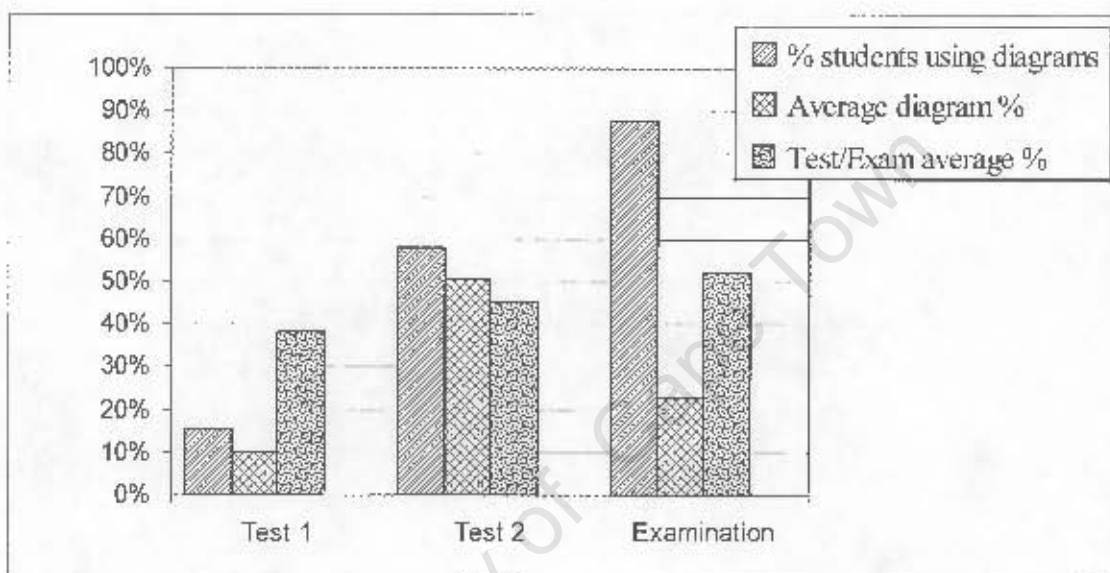


Figure 26. Progression during the course of the first semester of 2003 of the adoption of multi-representational problem solving techniques by Cape Technikon students. The chart also shows the average mark awarded in each test specifically for physics diagrams, as well as the overall class average for the test or examination.

The number of students using physics diagrams in formal tests increased steadily during the semester, as did the overall averages for these tests and the examination. The average of the marks awarded specifically for physics diagrams increased from Test 1 to Test 2, but declined in the final examination, possibly because fewer marks were awarded for physics diagrams in the examination, and the marking of these diagrams was done more strictly than in the class tests.

Nevertheless, many students' diagrams in response to context-rich questions in the final examinations in 2002 and 2003 reflected a considerable degree of sophistication.

Figure 27, Figure 28 and Figure 29 show examples of the use of axes, formal sign conventions and the appropriate recording of both known and missing data.

- 2.3 You are driving at night at 90 km/h up a slight hill when you see the taillights of a truck ahead of you. Suddenly you realise that the truck is not moving forwards (in fact it is rolling back down the hill towards you at a constant 2 m/s) and, when the truck is still 42 m away, you hit the brakes and begin slowing down at 6 m/s^2 .
- 2.3.1 Draw the complete Physics diagram of the situation which you would use to determine how long it takes (after you hit the brakes) before the truck smashes into you. Your diagram should include all the relevant variables which you know, as well as those which you would need to determine in order to find your answer.

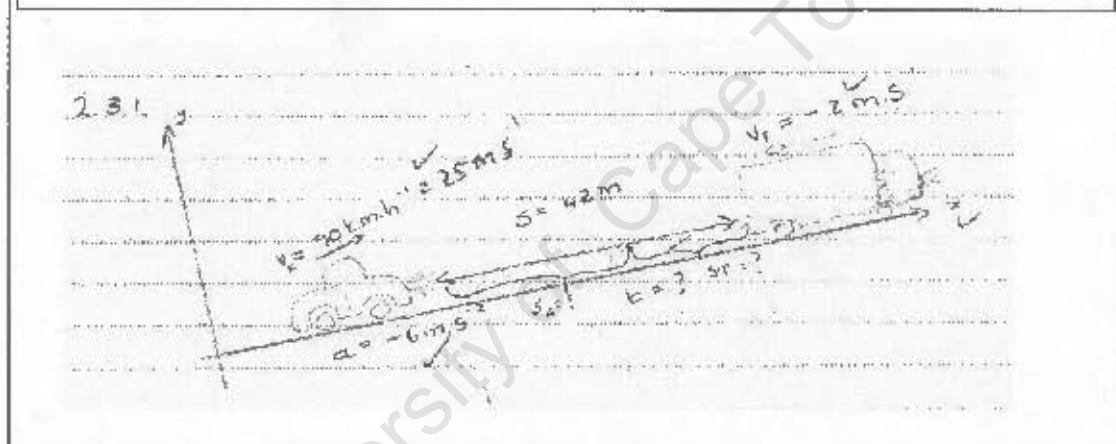


Figure 27. An example of a student's response to a question in the 2002 final examination, showing the extent and sophistication of the use of multi-representational techniques.

2.2 In the same instant that a Porsche races past him at 129.6 km/h, a speed cop sets off on his motorcycle, accelerating uniformly at 8 m/s^2 , to catch the speedster. After 5 s the traffic officer reaches his top speed, which he then maintains until he catches up to the car.

2.2.1 Calculate the motorbike's top speed.

2.2.2 Draw the complete Physics diagram of the situation which you would use to determine how long it takes (after the car passes him) before the traffic officer catches up to the car. Your diagram should include all the relevant variables which you know, as well as those which you would need to determine in order to find your answer.

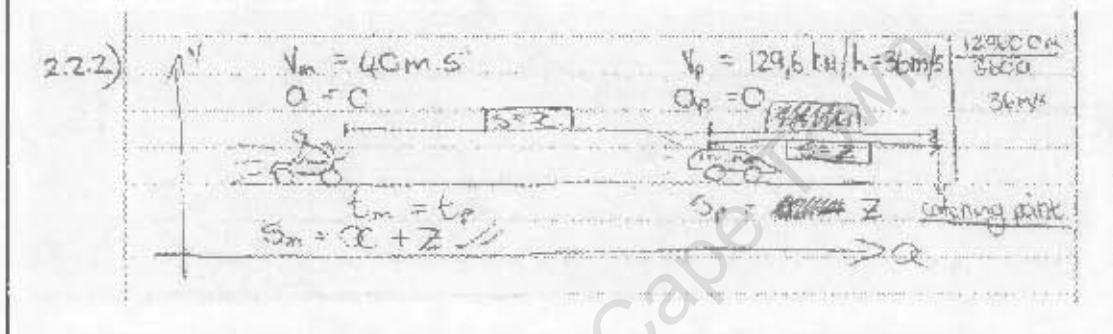


Figure 28. An example of a student's response to the second part of a question in the 2003 final examination, showing extensive use of multi-representational techniques.

- 3.1 You and your friends go sand sledding in the Hout Bay sand dunes. You climb up the front face of the dune (which you estimate makes an angle of 37° with the horizontal) to a height of 30 m. However, before you sit down on your piece of waxed hardboard and begin sliding down the dune (from rest), you decide you'd better first calculate how fast you'll be going when you reach the bottom!

If the coefficient of kinetic friction between sand and waxed hardboard is 0.16, determine how many kilometres an hour you'll be doing at the bottom of the dune.

3.1)

30m

37°

$v = ?$

$\mu_k = 0.16$

$\sum F = ma$

$F_f + w \sin \theta + F_N + w \cos \theta = ma$

$F_f + w \sin \theta = ma$

$F_f + w \sin \theta = \left(\frac{30}{10}\right)a$

$F_f + w \sin 37^\circ = 0.3w \cdot a$

$\therefore -0.16 F_N + w \sin 37^\circ = 0.3w \cdot a$

$\therefore -0.16 w \cos \theta + w \sin 37^\circ = 0.3w \cdot a$

$\therefore -0.16 w \cos 37^\circ + w \sin 37^\circ = 0.3w \cdot a$

$w (-0.16 \cos 37^\circ + \sin 37^\circ) = 0.3w \cdot a$

$(-0.16 \cos 37^\circ + \sin 37^\circ) = 0.3 \cdot a$

$\therefore a = 4.74 \text{ m/s}^2$

$u = 0$

$v = ?$

$s = 39.85 \text{ m}$

$\sin 37^\circ = \frac{30}{s}$

$s = 49.85 \text{ m}$

$v = ?$

1.3

Figure 29. An example of a student's response to a question in the 2002 final examination. Although the question does not stipulate the need for a diagram, the student makes full use of multi-representational techniques in reaching a correct numerical solution.

5.2.3. Feedback from students

This section reports on various items of qualitative, subjective feedback elicited from students by means of several questionnaires.

(a) Weekly Problem Set and teaching style evaluation

During the course of the semester students provided the lecturer with continual informal feedback about the Weekly Problem Sets and the cognitive conflict style of lecturing in the form of verbal comments and “one minute papers”. Much of this feedback was positive, and almost all of it was constructive, enabling the lecturer to make continual responsive adjustments to the problem set programme and his lecture delivery. In addition, a formal questionnaire (Appendix G) was specifically designed in 2003 to collect both closed and open-ended responses to several of the educational strategies implemented to reinforce the new multi-representational problem solving intervention (Section 4.4). The questionnaire was completed by 180 students towards the end of the semester's instruction.

A few informative quotes from the open-ended questions are included among those from the more general end-of-course evaluation questionnaire below (Section 5.2.3(b)).

Besides responses to questions about the peer tutors and the course mentor which are not relevant to this study, the 28 Likert-scale items in the questionnaire also elicited information regarding students' views on the Weekly Problem Set program and the lecturer's cognitive conflict style of teaching. This information is summarised in the form of an agree-disagree plot for the relevant questions (**Figure 30**).

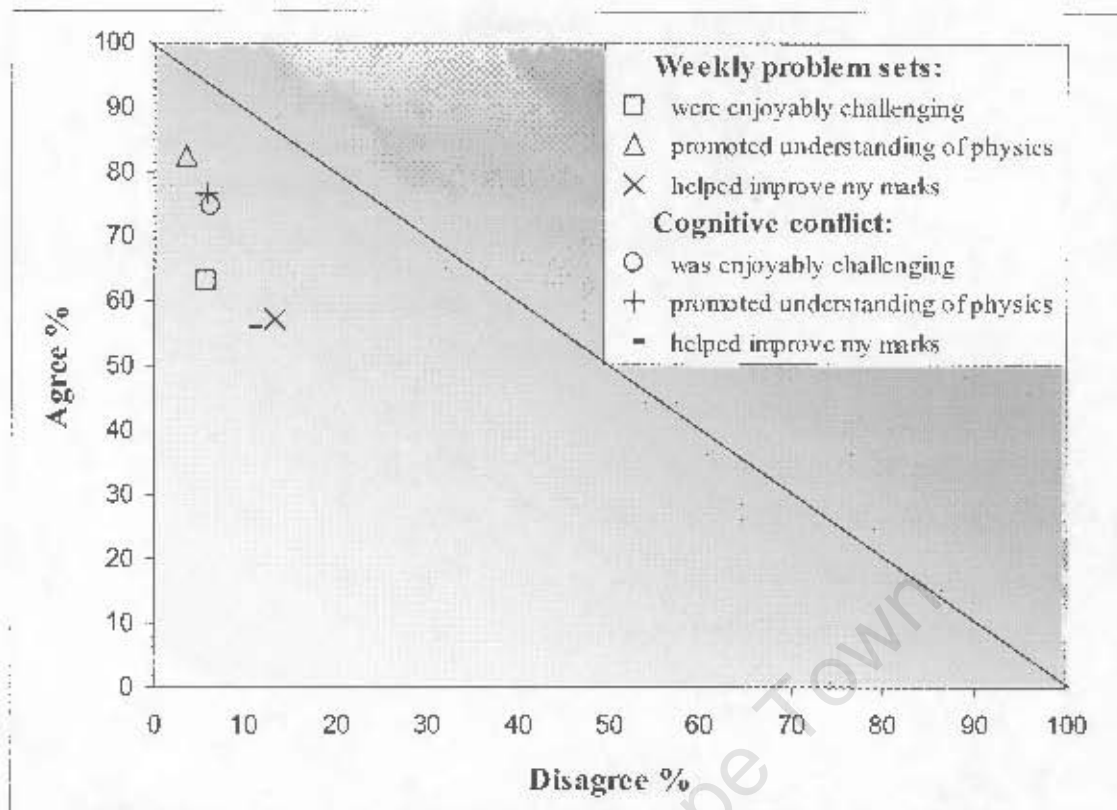


Figure 30. An agree-disagree plot of students' responses to selected questions from the Likert-scale feedback questionnaire concerning the Weekly Problem Set program and the cognitive conflict style of lecturing used in the course.

It can be seen from the plot that the majority of students believed that these two strategies were both enjoyable and effective in promoting understanding of physics. They were, however, less convinced of their impact on their actual course marks.

(b) End-of-course evaluation

At the end of the course, students were given a course evaluation questionnaire (Appendix F) based on the standard feedback questionnaire used as a matter of course throughout the Cape Technikon. While most of the Likert-scale items in the questionnaire deal with mundane aspects of the course and the lecturer (such as personal organisation, punctuality and clarity of diction) and will not be reported on here, students were also explicitly invited to comment (separately) on those aspects of the course and the lecturer which they liked and disliked.

Among these comments, as well as among the responses to the open-ended questions in the “Weekly Problem Set” questionnaire (Section 5.2.3(a)), were a considerable number in which students reported having developed far more positive attitudes towards physics during the course, with some students admitting that they had begun to enjoy the subject for the first time in all the years they had been grappling with it.

The following are verbatim examples of student comments:

- “For the first time, I actually enjoyed being in physics class.”
- “It was very interesting and I learned something for the first time in my life. Made me think more.”
- “What I like about physics is that helped me to understand thing clear which are in real life. [The lecturer] teaches his subject in a way that everybody can understand.”
- “The techniques taught.” [In response to “List those aspects you liked about the subject.”]
- “I hated physics at school, but here I started to like it and it became interesting because I understood everything better. A lot of things made more sense.”
- “I like the way the subject was presented as I was never taught physics as clearly as it was taught this year.”

(c) Post-instruction physics expectations survey

While the comments in Section 5.2.3(b) above deal with the general nature of the subject as a whole, student responses to another open-ended question included among the Likert-scale questions in the post-instruction physics expectations survey shed more light on the probable cause of this improvement in attitude towards physics. (The quantitative results from the Likert-scale items are reported in Section 5.2.1.)

The open-ended question on the post-instruction questionnaire was deliberately undirected, asking simply: “What are three things you learned from this course? Explain briefly.” Several responses to this question included explicit, positive references to the new, multi-representational approach to problem solving, such as:

- “...the best way that I’ve learned is that before attempting any problem you must have a diagram that represents what would you be busy with and it help a lot.”
- “Learn the meanings of the equations and drawing diagrams so that the problem could be easier to solve.”
- “Technique of Solving Problem (Diagrams then equate).”
- “Draw Pictures / Axis. Think before answer a question.”
- “Interpret a problem by graph or drawings.”

This level of awareness and acceptance of the general principles of the multi-representational approach to problem solving in physics was manifest in the increasing confidence with which students tackled physics problems and their improved attitudes towards the subject as reported in parts (a) and (b) of this section. Furthermore, these improvements in confidence and attitude coincided with marked improvements in the course pass rate.

5.2.4. Physics 1 pass rates

The pass rates for Physics 1 in the Faculty of Applied Sciences at the Cape Technikon between 1993 and 2003 are shown in Figure 31. The figure shows actual numbers of enrolled students, the number of those who passed and the percentage pass rate for each of the eleven years.

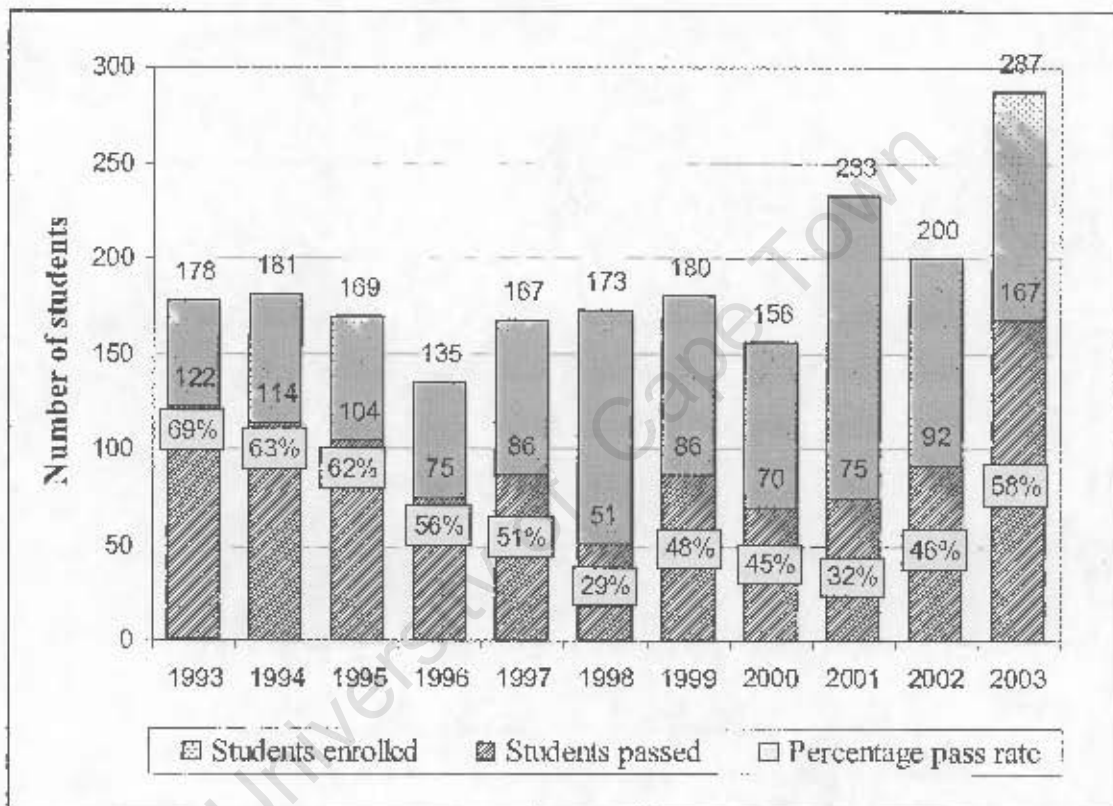


Figure 31. Physics 1 enrolment and passing statistics between 1993 and 2003. The percentage pass rates are shown in rectangles for each year.

Physics 1 enrolment figures remained roughly constant between 1993 and 2000, averaging about 170. If the anomaly of 1998 is ignored, the pass rate declined steadily from 69% to 45% during this period. After 2000, enrolment exceeded 200 for the first time, but the pass rate was initially even lower than before (allowing for the 1998 anomaly). Only once the new teaching intervention was introduced in 2002 and 2003 did the pass rate show signs of recovering.

5.3 Case studies

The following case studies serve to illustrate the individual responses of a few students to the course and particularly the new multi-representational problem solving strategies.

Student A attended a former Coloured Affairs senior secondary school in Beaufort West and attained an E symbol for Senior Certificate (Grade 12) Physical Science on the Standard Grade. He scored 55% in the Baseline Mathematics quiz when he first enrolled for Physics 1 in 2001, and 69% for the identical quiz when he re-enrolled in 2002. (The student attained a year mark of only 34% in 2001 and was not permitted to write the final examination that year.) The student was still not making use of diagrams by the time of the diagnostic kinematics test (Section 3.1.3) at the beginning of 2002 and scored only 23% in this test. In the first formal test of 2002, however, the student attained 50% of the drawing marks and 58% overall. This candidate scored very poorly in the pre-instruction physics expectations survey at the beginning of 2002, *actively* disagreeing with the expert answers in *all* categories, but his attitudes towards the subject improved considerably during the course of this, his second semester of physics, and he scored above the class average in the post-instruction survey (in all categories). In the final examination in 2002, where he made extensive use of formal physics drawings, he scored 65%.

Student B achieved very high scores (in the top 5% of the group) in both pre- and post-instruction physics expectations surveys in 2003, indicating sound cognitive expectations and epistemological beliefs, despite having achieved only an F on the Standard Grade in Senior Certificate Physical Science. His mathematics was poor: he attained a Standard Grade E symbol in Senior Certificate Mathematics and only 47% for the UCT Numeracy Competency Questionnaire (well below the 70% recommended by the Numeracy Centre for a career in the sciences). This student quickly adopted the new multi-representational problem solving approach and scored full marks for the required physics diagrams in both the first and second kinematics tests (Appendices H and I), achieving 53% and 48% respectively overall. Student B

passed Physics 1 at the first attempt in 2003 with a year mark of 64% and a final examination mark of 54%.

Student C attended an excellent girls' school in Cape Town, achieving Higher Grade E symbols for both Physical Science and Mathematics in Grade 12. She then followed several non-scientific careers (and began a family) before deciding to enrol at the Cape Technikon for a National Diploma in Food Technology in 2003. As a mature student (in her mid-twenties) she proved capable of metacognition and admitted early on that her mathematics was "rusty", although she did manage 60% on the Numeracy Competency Questionnaire (NCQ2003). She scored well on the pre-instruction physics expectations survey and did even better on the post-instruction questionnaire (scoring in the top 4% of the group). Similarly to student B, she scored full marks for the physics diagrams in both the first and second kinematics tests and her physics marks improved rapidly from 52% to 72%. She applied her new multi-representational problem solving skills in the final examination, but disclosed later that she had been distracted by very serious personal problems during the examination period. (She was in fact forced to suspend her studies for a semester). This could explain why she misread question 2.2.2 in the examination (Appendix J), proceeding beyond the stipulated pictorial stages of the problem. The time she wasted on a lengthy numerical solution resulted in her being forced to omit an entire question at the end of the paper and depressed her examination mark to 48%. (For the questions she did answer she averaged nearly 60%.)

Student D is a good example of a competent candidate whose experience of secondary school physics (where she achieved a Standard Grade B symbol at a good, Afrikaans medium school) was the probable cause of her inappropriate expectations of physics at tertiary level (she performed very poorly in the pre-instruction physics expectations survey). Despite an A symbol for Standard Grade Senior Certificate Mathematics, she scored only 59% on the NCQ2003 and 48% for her first kinematics test, where she persisted with purely numerical methods of problem solving. By the second test, however, she had adopted the multi-representational approach – she scored full marks for the pre-mathematical stages and her test mark improved to 62%. She attained nearly 80% of the physics diagram marks in the final examination, for

which she scored 67%. Her considerable improvement in the post-instruction physics expectations survey (moving from the bottom third of the group to the top quarter, with especial improvements in the Concept and Reality clusters) indicated the extent to which her cognitive beliefs about tertiary physics had improved.

Candidates with sound physics and mathematics backgrounds were also able to benefit from the new teaching strategy...

Student E achieved a B symbol for Physical Science on the Higher Grade in the Senior Certificate examinations and scored 79% for the basic numeracy quiz when he enrolled for Physics 1 at the Cape Technikon in 2002. After scoring 69% for the diagnostic kinematics test, he adapted well to the multi-representational approach and was awarded more than 90% of the drawing marks for the first formal kinematics test, in which he attained 71%. He obtained a very high mark for the pictorial stages in the final examination, finishing with 88% overall. Once again, this improvement in marks was mirrored by a marked shift in physics expectations scores from pre- to post-instruction. His scores improved considerably in all categories (except in the Mathematics cluster, where they were reasonably high to begin with), and he finished in the top 5% of the group.

To summarise, many students who adopted the new multi-representational approach to problem solving were generally shown by the physics expectations surveys to have developed more mature, more appropriate beliefs about what was required of them to master physics. This epistemological development, together with their ameliorated affective attitudes (as reflected in their responses to the several feedback questionnaires) manifested itself in measurably improved approaches to problem solving and a higher success rate in terms of performance in the course as reflected by their final marks.

6. Discussion

6.1 Summary of results

The present work shows that first time entering students to the Faculty of Applied Sciences at the Cape Technikon are characterised by extremely poor numeracy, mathematical and reasoning skills. These shortcomings are compounded by inappropriate and unrealistic epistemological beliefs about learning physics (as well as by other circumstantial and social factors). Consequently, prior to 2002, despite sound, enthusiastic teaching and several *ad hoc* teaching interventions (such as tutorial sessions and organised, cooperative group work), students lacked confidence in their abilities to succeed in physics and remained demotivated and unconvinced of the relevance of this demanding, one-semester-only, non-major subject. As a result, the Physics 1 pass rate declined until it averaged only 38% during the four years prior to 2002.

During the course of the present study, in 2002 and 2003, students were given explicit instruction and guidance in the use of a new, research-based technique of multi-representational problem solving, as a result of which, as they gradually adopted the new strategies, their epistemological beliefs and their expectations about learning physics improved significantly.

The increase in the Physics 1 pass rate during this same period may be ascribed, at least in part, to this epistemological amelioration.

6.1.1. Students' initial numeracy skills

The results of Baseline Mathematics quiz administered annually between 1999 and 2002 indicate that incoming Cape Technikon students are *consistently* lacking in the required *basic* mathematical skills such as computation, spatial perception and simple algebra.

The results from the University of Cape Town's Numeracy Competency Questionnaire, NCQ2003 (as administered to first year Cape Technikon students in 2003), confirmed this finding, providing a more sophisticated probe into students' shortcomings. The results showed that all but a very small percentage (5%) of the 2003 Technikon group lacked a level of functional quantitative literacy "appropriate for students intending to study in a Science faculty" (Frith *et al.* 2003b). Furthermore, Sections B and C of the questionnaire revealed that very few these students were capable of either using mathematics in everyday "relevant contexts", or successfully manipulating formulae – both of which skills are essential for the solution of most physics problems.

6.1.2. Pre-instruction physics expectations

Despite all the above-mentioned mathematical limitations, students' responses in several categories of the pre-instruction physics expectations survey made it clear that the vast majority of students are conditioned by their secondary school experiences in physics to rely heavily on the traditional formula-centred, numerical approach to problem solving. This experience, coupled with other circumstantial and social factors, foments negative, often fearful feelings towards Physics 1, and many incoming students are pessimistic from the outset about their chances of mastering the subject at tertiary level.

In addition to students' views of the role of mathematics in physics, the pre-instruction expectations survey uncovered several other interesting epistemological beliefs about physics on the part of incoming students, including the extent to which they expect to be taught (passively) a subject made up of a disjointed collection of facts, concepts and algorithms, with little connection to their everyday experience of the real world. In this regard, at least, the Technikon students appear to be very similar to their counterparts in the United States, as shown by Redish *et al.* (1998).

6.1.3. Initial levels of scientific reasoning

In other developmental respects, however, the Cape Technikon students appear to be lagging behind their counterparts in the United States. While Lawson reported that 41% of the 922 non-physics major freshman-level students he tested were operating at the "hypothetical/deductive" level of scientific reasoning (with another 47% "in transition" to this phase) (Lawson 1992), administering Lawson's Classroom Test of Scientific Reasoning to the Cape Technikon Physics 1 students revealed that only 6% of the local students have yet begun to operate at the "hypothetical/deductive" level by the time they enrol for scientific diplomas in the Faculty of Applied Sciences (with about another 40% "in transition").

These results served to further underscore the likelihood that, simply exposed to "more of the same" traditional mathematical approaches to teaching physics, the Cape Technikon students would be unlikely to improve their performance in and their attitudes towards learning physics.

6.1.4. Adoption of the new multi-representational approach to problem solving

Analysis of students' answers to questions in the Weekly Problem Sets, class tests and the final examination during the course of this study revealed that most students were

able to adapt to the new multi-representational approach to problem solving, making increasing use (and increasingly sophisticated use) of the strategy as the semester progressed.

In the final examinations in both 2002 and 2003 students showed themselves capable of using multi-representational strategies to answer context-rich questions which were far more complex and demanding than any which had been set in previous Physics 1 examinations.

6.1.5. Post-instruction attitudes towards physics

Most significantly for this study, the results of the post-instruction physics expectations survey in 2002 revealed that, as a result of the new teaching intervention, Cape Technikon students underwent a positive shift in epistemologies – a shift quite at variance with the shifts measured after a semester's physics instruction at six different United States institutions (Redish *et al.* 1998). This uncharacteristically positive shift was recorded again with the 2003 intake, and is all the more remarkable in the light of the Cape Technikon students' initial trepidation and hostility towards physics.

Similar improvements in attitude are discernible from comments made about the course, the teaching methodology used and physics in general, by students during the various feedback and evaluation exercises conducted during each semester of instruction. The comments reflect genuine appreciation of the extent to which multi-representational problem solving can facilitate problem solving, even among students with very poor mathematical skills.

6.1.6. Final course results

The same lecturer (i.e. the researcher) taught all the Physics 1 classes in the Faculty of Applied Sciences at the Cape Technikon between 1993 and 2003. For fifteen years

prior to that, he taught Physical Science to Grade 12 level at various secondary schools in Cape Town, so by 2002 he had accumulated two and half decades of unbroken experience of teaching physics. Furthermore, since the lecturer was awarded the Cape Technikon's Distinguished Teacher Award in 2000, the quality of his physics instruction can be assumed to be above average.

Nevertheless the Physics 1 pass rate at the Cape Technikon fell almost steadily from 1993 to 2001. Aware of the social, historical, economic and academic characteristics of technikon students which might account for this decline (and which are described in Sections 2 and 3 of this study), the lecturer made every effort to "teach harder", but since this simply amounted to "more of the same", in the end it had palpably little effect on the average academic performance of students.

In the light of the above, the improvement in the Physics 1 pass rate in 2002 and 2003 (the years of the new research-based teaching intervention) is significant.

Furthermore, the various benchmarking studies performed on the student intakes of these two years make it clear that the improvement cannot be ascribed to better-prepared, more numerate, or more scientifically literate students.

The number of students who passed Physics 1 in 2003 far exceeded the number "predicted" by the results of Numeracy Competency Questionnaire, which had identified only 5% of the class as being numerate enough to merit entry into a traditional science-based curriculum. However, in keeping with Meltzer's findings regarding the correlation between students' pre-instruction mathematics skills and their learning gains in physics (Meltzer 2002), the NCQ instrument did prove accurate in predicting students' *relative* chances of passing Physics 1, as shown by the correlation between students' score categories on the pre-instruction numeracy quiz and their chances of passing Physics 1 at the end of the semester (Figure 32). Students who achieved in the 40-49% range (or above) on the NCQ had a better than even chance of passing Physics 1, while students who scored less than 30% were extremely unlikely to pass the subject at the end of the semester.

It may be argued therefore that, had this intake of students been instructed in the more traditional, mathematically-centred ways of physics rather than the new multi-representational approach, the pass rate would indeed have been much lower (i.e. more in line with the prevailing trend).

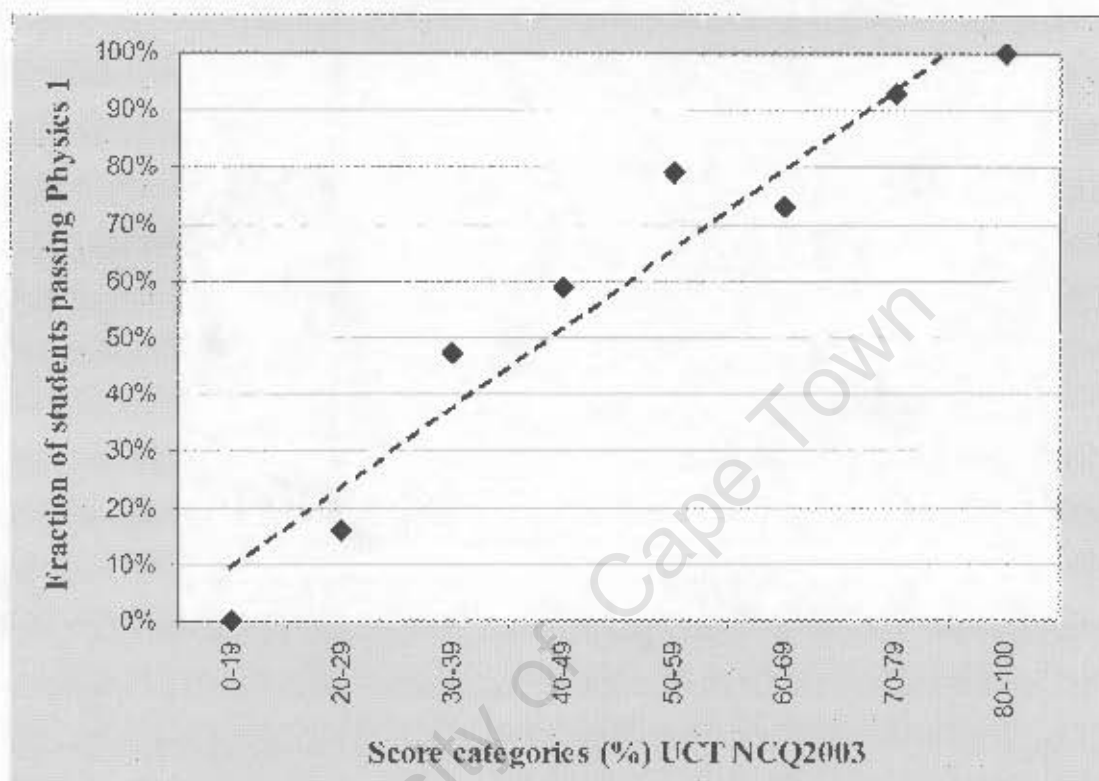


Figure 32. Relationship between 2003 students' score categories on the pre-instruction numeracy quiz (NCQ2003) and the fraction of students in each category who passed Physics 1 at the end of the semester. The dashed line is a least squares fit to the data.

Finally, the case studies in Section 5.3 shed further light on the interrelationship between students' adoption of the new multi-representational problem solving strategies, their subsequently increased confidence in tackling complex physics problems, and their ultimately more successful mathematical performance, all of which led to improved course marks.

6.2 Reflections on implementing the new curriculum

Several issues militated against complete adoption by the students of the new problem solving strategies.

6.2.1. Conservatism

A common problem facing any new intervention is the conservatism which inevitably arises from the pressure of final examinations. Even students who are persuaded to try the new techniques during the course of instruction sometimes revert to tried and tested algorithms when their final marks are in the balance. “Most students choose to trust their practical experience and adjust their behaviour in a manner that will get them a good grade even if they believe that alternative behaviour would result in better understanding” (Henderson *et al.* 2003, p. 165).

All Faculty of Applied Sciences students whose diploma programme dictates that they enrol for Physics 1 encounter the subject in their first semester of tertiary study, concurrent with – not subsequent to – a first mathematics course, and furthermore at a time when they are still making enormous social adjustments. A 15-week course in physics, in an environment overwhelmingly different to that of secondary school, is an extremely short and isolated forum in which to expect students to buy into, adopt, practise and perfect a totally new approach to problem solving. New paradigms need time to be assimilated and internalised before they become part of a student’s stock-in-trade, and the benefits of these deeper approaches do not always show up early in actual marks.

6.2.2. Ignorance of physics pedagogy

One semester is also a very short time in which to attempt to free students from the conditioning effected by 12 years in a secondary school education system in which they are often rewarded simply for sitting passively while the teacher “teaches”. In general, South African secondary school practice discourages large-scale active participation by pupils, who consequently have to make great adjustments (in a short time) to meet the self-study requirements of tertiary education.

It is impossible to master physics without engaging actively in the process of constructing personalised conceptual knowledge, partly as a result of developing more expert-like problem solving techniques. In this regard physics stands apart from most other Cape Technikon offerings (certainly first year offerings) which require mainly only first order cognitive skills such as memorisation and recall – skills which *are* inculcated at secondary school level. Physics 1 is unusual in the extent to which it requires students to develop second and third order skills, by, for example, transferring problem solving skills from one context to another, and, further, synthesising isolated bits of information into “chunks” of knowledge in order to grow a single, reliable and consistent model of the physical world around them. In terms of the distinction made by Ryle (1949, cited in White 1988, p. 33), where other subjects concern themselves with “knowing that”, physics is primarily concerned with “knowing how”.

Even programme coordinators and other administrators sometimes fail to appreciate these distinctions. They tend to be suspicious of the “different teaching procedures” implemented in Physics 1 and believe that the subject’s poor pass rates could be improved simply by “better” (i.e. more traditional) teaching. At other times educational concerns are completely subducted by financial and political considerations such as subsidies or continued programme viability, both of which are inextricably linked to throughput rates.

Student feedback has revealed that, wittingly or unwittingly, these administrators are sometimes guilty of conveying their own narrow epistemological beliefs to students, thereby undermining attempts to develop genuine life-long learning skills and attitudes in the course of Physics 1. Students have been led to believe that, the stated objectives of Physics 1 notwithstanding, they can pass the subject purely on the strength of their performance in other (content-rich) subjects, or, if necessary, by being eventually “put through” through the administrative intercession of a programme convenor or other administrator.

The ethos thus created feeds the passive “culture of entitlement” increasingly prevalent among first year tertiary students in South Africa, making it difficult to motivate them to engage meaningfully in effortful learning activities, such as those demanded in the development of robust problem solving skills.

6.3 Limitations of this study and further work

It is difficult, if not methodologically unsound, to infer a strong causal relationship between any one teaching intervention and students’ subsequent academic improvement. Firstly, for ethical and logistical reasons, educators seldom have the luxury of being able to maintain a control group while subjecting a test group to a single specific intervention. For any given year group, educators will implement as many supportive and possibly beneficial teaching strategies as they can, the effects of which may also be as yet untested. Furthermore, successful generic interventions applied in other subjects (e.g. training in note taking, time management, etc.) will inevitably spill over into the experimental group, further impacting academic results.

Secondly, there are many ways in which “academic improvement” can be artificially manipulated. Levels of difficulty inevitably differ from one examination to another and standards are relative, being subject to both natural gradual readjustment and political pressure. Physics 1 at the Cape Technikon is subject to only internal moderation and it is consequently quite possible to effect considerable mark adjustments if these are deemed expedient.

Further work would be needed to establish a definite causal relationship between explicit multi-representational problem solving training and improved academic performance in physics.

Mention was made in Section 4.3 of the use of worksheets for developing students' conceptual and pre-mathematical understanding of kinematics quantities such as velocity and acceleration. In practice, only very limited use was made of such worksheets in this study, as it was found that many students worked so slowly and laboriously through the examples that the graphical representations became an end in themselves instead of quick and simple devices to facilitate students' grasp of the problem situation. By the time dynamics was introduced, worksheets were abandoned, and students received training in the construction of free-body diagrams purely through the modelling of examples by the lecturer on the chalkboard. Perhaps the use of such formal worksheets may be more appropriate and useful in foundation courses running over a longer period of time than one semester. Care would nevertheless still need to be taken in order to prevent students losing sight of the wood for the trees.

In the present study, students were trained to progress linearly from the text of a problem, through the pictorial and diagrammatic representations to the mathematical representation. Time constraints precluded experimentation with the "shuffling" of these stages, as suggested by Alesandrini (1981) in order to develop even more robust problem solving competencies. Further work needs to be done on testing the usefulness of, for example, presenting students with a mathematical representation and asking them to "work backwards" in order to suggest possible pictorial (or real life) situations (or even textual problems) which may have led to the mathematical statement.

Finally, there is much scope for investigation into the overarching issue of language, which has received only the briefest mention in the present work, despite the fact that the very first step of most multi-representational problem solving strategies involves interpreting a language-based depiction of the problem. The issue is particularly

critical in the South African context, where no less than eleven official languages are recognised and accorded (at least theoretically) equal status. The recently revised language policy of the Cape Technikon (historically a dual English and Afrikaans medium institution) declares English to be the primary medium of instruction, but also makes reference to providing assistance to students in their mother tongue “wherever this is possible or feasible”. In practice, however, besides the provision of a few tutors capable of speaking one or two African languages, it is usually only Afrikaans speaking students who receive extra consideration in the way of having their course notes, tests and examinations presented in Afrikaans in addition to English (although even this is no longer currently common practice at the Cape Technikon).

The problem is exacerbated by the increasing number of foreign students enrolling at the Cape Technikon. Many of these come from other African countries, both nearby and distant, and may speak a local dialect and/or a “colonial” language such as French or Portuguese. The Technikon also recently entered into a special educational relationship with the People’s Republic of China, and several Chinese speaking students are currently enrolled in the Faculty of Applied Sciences. Having said this, however, there is anecdotal evidence to suggest that foreign students in fact often fare far better academically than local students at the Technikon. Greg Pastoll (2002) has suggested that the so-called language problem is less to do with “lack of command of language” than it is to do with “muddled thinking”. “A muddy thinker will express himself muddily in any language, but a clear thinker will always take the trouble to be clear, using the few words at his disposal” (p. 75).

Apologists who persist in excusing local students on the grounds that the “language problems” they experience are due to historical disadvantages rather than a lack of effortful commitment to making meaningful sense of the world around them, are perhaps helping to perpetuate students’ inferior reasoning and functioning by drawing attention away from the real causes and, hence, effective solutions. Since “language problems” is one of the most oft-cited reasons for students’ poor performance at tertiary level, further research into the true nature and causes of the problem would be very valuable.

6.4 Conclusion

During the course of first year tertiary physics, as problems become more complex, or the context becomes unfamiliar, students discover that their familiar secondary school algorithmic approaches begin to fail them repeatedly. With naïve ideas about what it means to study physics, and ill-equipped to reason logically, they become increasingly frustrated, resentful and demoralised. Many, unused to the responsibilities of tertiary study, externalise their problems, attributing the failure of their previous strategies to a perceived intent on the part of the lecturer to deliberately cause them to fail by “not teaching properly” or “making the subject unnecessarily difficult”.

The tension between poor numerical ability and an over-dependence on numerical methods is almost certainly one of the main causes of poor first year physics pass rates at tertiary level, but is seldom explicitly addressed by tertiary lecturers. Educators at this level perennially assume that incoming students have been taught problem solving skills at secondary school level, or, because they have elected to study science, that these students have natural numerical and algebraic abilities. This is seldom the case, however, even in developed, first world countries with well-established secondary schools, well-staffed with scientifically qualified educators. As Hewitt (1982) cautions, it is a mistake to assume that just because it is easy to *teach* physics mathematically, it is easy to *learn* it mathematically.

Only a carefully planned, properly structured, research-based teaching intervention specifically designed to address these particular shortcomings and attitudes has proved capable of effecting significant change in such unpromising conditions.

Equipping students with multi-representational skills appears to allow them to step back from the required mathematics long enough to see “the bigger picture”, that is, the true nature of the problem, the underlying principles and concepts, and possible ways of solving it. This study shows that it is possible to train students in such unfamiliar skills in a relatively short period of time, even within the context of large classes of mixed ability.

As students gradually learn to use the new pre-mathematical strategies, they gain confidence in their ability to understand and solve physics problems. As they develop more conceptual insight through the use of alternative tools, such as physics diagrams, they learn to choose more appropriate mathematical representations and they make fewer mistakes in the numerical stages of problem solving.

Students enrolled in the Faculty of Applied Sciences at the Cape Technikon are not studying to become physicists. They are, however, all studying to become scientifically literate, and as such it is vital that they be given substantive grounding in the fundamentals of science, that is, its fundamental content, its ways of thinking and reasoning, and, above all, its methodologies.

The explicit training in pre-numerical, qualitative and conceptual skills carried out as part of the multi-representational approach introduced in the course of this study has been demonstrated to be an effective means of imbuing even weak students with scientific procedures and principles. Despite their poor numeracy and reasoning skills and their initially inappropriate beliefs about learning physics, many Cape Technikon students found that the new approach enabled them to develop a deeper, more satisfying understanding of the world around them. These methodologies and competencies pave the way for further authentic life-long learning.

Appendices

University of Cape Town

FACULTY OF APPLIED SCIENCES

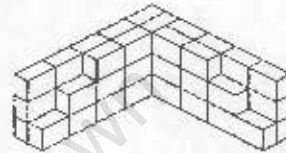
PHYSICS BASELINE MATHEMATICS



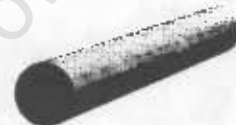
- Choose that answer which in your opinion is the correct or best answer and mark the appropriate block on the answer sheet provided.
- If you are sure of your answer, mark also the block containing the question mark.
- Use only a PENCIL on your answer sheet.
- In the case of a wrong answer erase the pencil mark completely.

1. How many bricks were used to build the wall in the adjacent sketch?

A 44 B 46
C 47 D 48



2. The adjacent pipe is cut along the dotted line and folded down flat. Which one of the following shapes will you see?



3. What fraction of the adjacent figure is shaded?

A $\frac{1}{3}$ B $\frac{1}{2}$ C $\frac{2}{3}$ D $\frac{3}{4}$



4. To tar a rectangle 4 m by 3 m a builder needs 9 wheelbarrow loads of tar. How many wheelbarrow loads will he need to tar a rectangle 8 m by 6 m?

A 13,5 B 18 C 27 D 36

5. A cube has six faces (facets). How many faces does this three-dimensional letter C have?

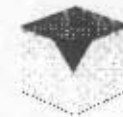
A 7 B 9 C 10 D 14



6. If \star is an odd number, which one of the following is also an odd number?

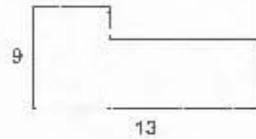
A $\star \times 2$ B $\star + 2$ C $\star + 3$ D $\star - 1$

7. The adjacent picture shows a wooden cube with one corner cut off and shaded. Which one of the following drawings shows how this cube will look when viewed directly from above?



8. All sides of this figure are either horizontal or vertical. How far is it around the figure?

A 22 B 44
C 52 D impossible to say



9. What is the approximate mass of an empty minibus taxi?

A 1 450 kg B 2,460 kg C 5 tons D 6 400 g

10. The numbers in this row are listed according to a certain pattern. Which number is missing?

7 ; 21 ; ... ; 189

A 28 B 35 C 42 D 63

11. Which of the following is NOT equivalent to 14%?

A 0,014 B $\frac{7}{50}$ C $\frac{140}{1000}$ D 0,140

12. A piggy-bank holds equal numbers of 50-cent coins, 20-cent coins and 10-cent coins. How much money is there in the piggy-bank if it holds eight 50-cent coins?

A R4.00 B 400 cents C R6.00 D R6.40

13. A pile of 50 sheets of paper is 0,5 cm thick. How thick is one sheet?

A 0,1 mm B 1 mm C 0,001 cm D 0,025 cm

14. Each pizza supplied by a restaurant consists of 8 slices. How many pizzas must 16 students buy if each one wants to eat 3 slices?

A 6 B 8 C 16 D 24

15. A driver used 40 litres of petrol to travel the distance of 800 km from Cape Town to Port Elizabeth. How many litres of petrol will he use to travel the 300 km from Port Elizabeth to East London?

A 15 B 20 C 25 D 30

16. A snail which is 5 cm long glides forward at a steady pace. It covers a distance of 5 cm every minute. How long will it take the snail to pass *completely* through a pipe which is 25 cm long?

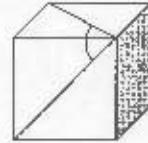
A 2,5 min B 5 min C 6 min D 8 min



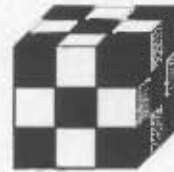
17. The mass of a container with sugar was 13 kg. After one third of the sugar had been used, the mass of the container with the rest of the sugar was 9 kg. What was the mass of the empty container?
- A 1 kg B 4 kg C 10 kg D none of these
18. In 10 years time the combined ages of four sisters will be 100. What will the combined ages be in 5 years time?
- A 15 B 50 C 80 D 95
19. A cricket and a flea decide to hop up a flight of 12 stairs. The flea takes two steps in one hop and the cricket takes 3 steps in one hop. On how many steps will both the flea and the cricket land?
- A 2 B 3 C 4 D 6
20. A cooldrink costs R2. You get 50c when returning an empty bottle. Andile has R20 to spend on cooldrinks. What is the maximum number of cooldrinks he can buy?
- A 10 B 12 C 13 D 14
21. Four children play tennis. Each child plays each of the others once. How many matches are played?
- A 4 B 5 C 6 D 12
22. Gina has a 4-digit combination which opens her locker padlock. She remembers that the digits are 3, 5, 7 and 9, but has forgotten the correct order. What is the maximum number of guesses she would have to make to try to open her lock?
- A 16 B 24 C 64 D 256
23. Half of 10^{-8} is
- A 5^{-8} B 10^{-1} C 5×10^{-8} D 5×10^{-9}
24. A boat sails from point X to point Y on a bearing of 079° . In what direction must it sail to get back to X from Y?
- A 079° B 169° C 259° D 281°
25. A string is wound around a circular rod exactly four times, creating a helix from one end of the rod to the other. What is the length of the string if the rod has a length of 12 cm and a circumference of 4 cm?
- A 16 cm B 20 cm C 24 cm D 28 cm



26. The diagonals on two adjacent faces of a cube meet at one vertex, as shown. What is the size of the angle between the diagonals?
 A 45° B 60° C 90° D 120°



27. A large cube consists of alternate black and white cubes, as shown in the figure. How many white cubes are there in the large cube?
 A 9 B 12
 C 13 D 17

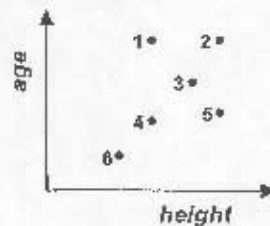


28. A boy and a girl run a 100 m race, which the boy wins by 5 m, so they decide to race again, this time with the boy starting 5 m behind the starting line. If they each run at the same speed they ran before (and their accelerations are ignored),
 A the boy will win by 25 cm
 B the boy will win by 50 cm
 C the boy and the girl will tie
 D the boy will lose

29. The people below are represented by six points on the graph, according to their heights and ages. Which point represents Dawid's height and age?

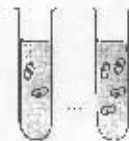


Anna Brenda Cathy Dawid Enoch Fahiemu



- A 1 B 3 C 4 D 5

30. Two amoebas are placed in a test tube. They reproduce by splitting themselves in two, a process that takes five minutes. After four hours they have filled the test tube. How long would it take a single amoeba in the same quantity of water to do the same?



- A 4 h B 4 h 5 min C 6 h D 8 h



If you have finished... A father and son have the same two digits in their ages, but with the digits reversed. Nine years ago, the father was twice as old as the son. How old are they now?

[Show your working on the back of your answer sheet.]

FACULTY OF APPLIED SCIENCES

CLASSROOM TEST OF SCIENTIFIC REASONING



CAPE TECHNIKON

First name: _____ Surname: _____

Course code: _____

Date:

INSTRUCTIONS

- This is a test of your ability to apply aspects of scientific and mathematical reasoning to analyse a situation, make a prediction, or solve a problem.
- In some questions you will be asked to show your work, or explain your answer, or both. Try to answer as completely as you can in the spaces provided. In some cases these explanations are more important than your actual answer.
- Use only a PENCIL on your answer sheet.
- When the question provides multiple answers, CIRCLE the letter next to the best answer and explain your selection.

Eg: How important do you think Physics 1 is to your future career?

- A Physics 1 is essential training for my future career!
 B Physics 1 is not really important.
 C Physics 1 is a waste of time.

Physics is the most fundamental of all the sciences. It trains you to think clearly and logically so you can become an excellent problem solver.

- If you do not fully understand what is being asked in a question, please ask the invigilator for clarification.

DO NOT TURN the page over before the starting time

MOENIE omblaai voordat die aanvangstyd is.

1. Suppose you are given two balls of clay of equal size and shape. The two balls are also of equal weight. One of the balls is flattened into a pancake-shaped piece. Which of the following statements is correct?

- A The ball weighs more than the pancake-shaped piece.
- B The two pieces weigh the same.
- C The pancake-shaped piece weighs more than the ball.

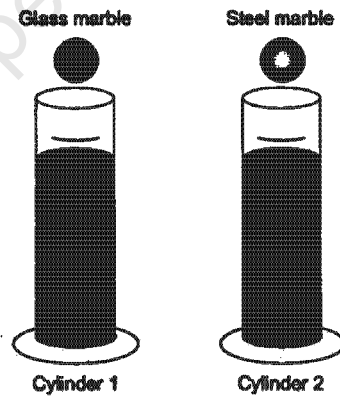
Please explain your selection.

2. The two cylinders in the sketch are filled to the same level with water. The cylinders are identical in size and shape. Also shown are two marbles, one made of glass and one made of steel. The marbles are the same size, but the steel one is much heavier.

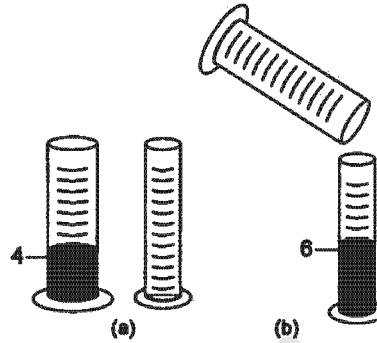
When the glass marble is put into Cylinder 1, it sinks to the bottom and the water level rises to the 6th mark. If we put the steel marble into Cylinder 2, the water will rise

- A to a lower level than it did in Cylinder 1
- B to a higher level than it did in Cylinder 1
- C to the same level as it did in Cylinder 1

Please explain your selection.



3. The wide and narrow cylinders in the sketch have equally spaced marks on them. Water is poured into the wide cylinder up to 4th mark, as shown in (a). This water rises to the 6th mark when poured into the narrow cylinder, as shown in (b).



Water is now poured into the wide cylinder up to the 6th mark. How high would this water rise if it were poured into the empty narrow cylinder?

Answer: _____

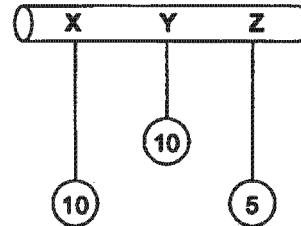
Please show (or explain) how you arrived at your answer.

4. Water is now poured into the *narrow* cylinder (described in Question 3 above) up to the 11th mark. How high would this water rise if it were poured into the empty wide cylinder?

Answer: _____

Please show (or explain) how you arrived at your answer.

5. The sketch shows three strings hanging from a bar. The strings have metal weights hanging from their ends. String X and String Z are the same length, but String Y is shorter. A 10-unit weight is attached to the end of String X. A 10-unit weight is also attached to the end of String Y. A 5-unit weight is attached to the end of String Z. The strings and their weights can be swung back and forth, and the time it takes for them to make a complete swing can be measured.



Suppose you wanted to find out whether the length of the string has an effect on the time taken for a complete swing... Which strings would you use to find out?

Answer: _____

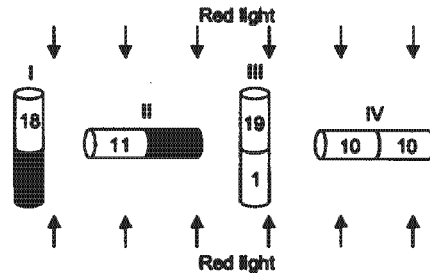
Please explain why you chose the strings you did.

6. Suppose you wanted to find out whether the amount of weight attached to the end of a string has an effect on the time taken for a complete swing... Which of the strings in Question 5 above would you use to find out?

Answer: _____

Please explain why you chose the strings you did.

7. Twenty flies are placed in each of four glass tubes shown in the sketch. The tubes are sealed. Tubes I and II are partly covered with black paper; Tubes III and IV are not covered. The tubes are suspended in mid-air as shown and then exposed to red light for five minutes. The numbers on the tubes indicate the number of flies in the uncovered part of each tube.

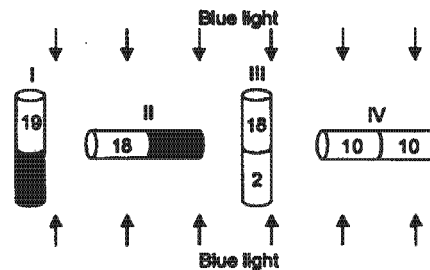


This experiment shows that flies respond to (*respond* means to move toward or away from)

- A red light but not to gravity
- B gravity but not to red light
- C both red light and gravity
- D neither red light nor gravity

Please explain your selection.

8. In a second experiment similar to the one in Question 7 above, blue light was used instead of red. The results are shown in the adjacent sketch. These data show that flies respond to



- A blue light but not to gravity
- B gravity but not to blue light
- C both blue light and gravity
- D neither blue light nor gravity

Please explain your selection.

9. Six square pieces of wood are put into a cloth bag and mixed. The six pieces are identical in size and shape, but three pieces are red and three pieces are yellow. Suppose someone reaches into the bag without looking and pulls out one piece... What are the chances that the piece is red?

Answer: _____

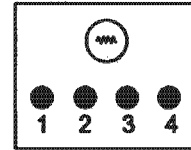
Please show (or explain) how you arrived at your answer.

10. Three red square pieces of wood, four yellow square pieces and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces and three blue round pieces are also put into the bag. The bag is then shaken. Suppose someone reaches into the bag (without looking or feeling for a particular shape) and pulls out one piece... What are the chances that the piece is a red or blue circle?

Answer: _____

Please show (or explain) how you arrived at your answer.

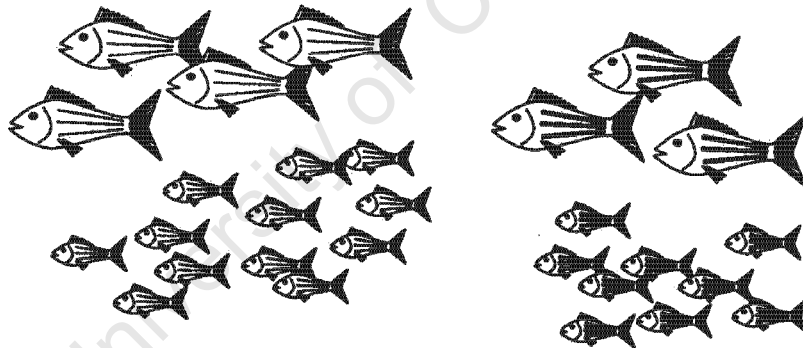
11. The sketch shows a box with a light bulb and four buttons numbered 1, 2, 3, and 4. The bulb will light only when the correct button or correct combination of buttons is pushed at the same time. Your problem is to work out which button (or combination of buttons) must be pushed to light the bulb.



Make a list of all the combinations of buttons you would push to figure out how to make the bulb light.

_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____

12. The fish in the drawing below were caught by a fisherman, who noticed that some of the fish were big and some were small. He noticed also that some had wide stripes, while others had narrow stripes. This made the fisherman wonder if there was a relation between the size of the fish and the width of their stripes.



Do you think there is a relation between the size of the fish and the width of their stripes?

- A Yes B No

Please explain your choice.

PHYSICS QUESTIONNAIRE

- **Items 1 to 20 are statements which may or may not describe what you believe about Physics. You are asked to rate each statement by choosing a response between A and E and ringing the letter of your choice on the answer sheet provided.**
- **PLEASE DO NOT MAKE ANY MARKS ON *THIS SHEET*.**
- **Do not over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple.**
- **Work quickly. If you do not understand a statement, leave it blank.**
- **If you do understand, but have no strong opinion either way, choose C.**
- **If an item combines two statements and you disagree with *either* one, choose A or B.**

1. Learning physics helps, or *will* help me understand situations in my everyday life.
2. In doing a physics problem, if my calculation gives a result which differs significantly from what I expect, I would just have to trust the calculation.
3. To understand physics, I expect to think about my personal experiences and relate them to the topic being analysed.
4. If I couldn't remember a particular equation needed for a problem in an exam there would be nothing much I could do (legally!) to come up with it.
5. To understand physics it is important to be able to use many different representations (ie graphs, tables, drawings etc) to describe the same situation.
6. If I came up with two different approaches to a problem and they gave different answers, I would not worry about it. I would just choose the answer that seemed more reasonable.
7. Physics is related to the real world, but you can understand physics without thinking about that connection.
8. Physical laws have little relation to what I experience in the real world.

9. Tami just read something in her physics textbook which seems to disagree with her own experiences. But to learn physics well, Tami shouldn't think about her own experiences; she should just focus on what the book says.
10. Often, a physics principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in physics is supposed to make sense.
11. If a problem in an exam is not fairly similar to one I've already done, I don't think I would have much of a chance to be able to solve it.
12. When handing in a physics test, you can generally have a correct sense of how well you did – even before talking about it with other students.
13. To really help us learn physics, the lecturer should spend more time giving us facts instead of spending time on concepts and theory.
14. To succeed in physics it's more important to be able to memorise large quantities of information than it is to make sense of the underlying ideas.
15. If the physics lecturer gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn physics without doing lots of sample questions and practice problems on their own.
16. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially written problems, but not for most ordinary problems.
17. To understand physics, the formulae (equations) are really the main thing. The other material is mostly to help you decide which equations to use in which situations.
18. Although the formulae aren't "tested" directly, correct and clever use of formulae is perhaps the main thing needed to do well in tests.
19. Some formulae summarise key concepts.
20. Although the formulae sometimes don't help you work out how to solve problems, learning them can increase your problem-solving speed.

21. If you had only very limited time to study, which of the following options would you choose?

- A Learning only a few basic formulae, but understanding them really well.
- B Learning all the formulae from the relevant chapters, but not understanding them too well.
- C A mixture of A and B, but more A than B.
- D A mixture of A and B, but more B than A.
- E An equal mixture of A and B.

22. The following is a discussion between two students who disagree with each other.

Brandon: A good physics textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit", because they're not really separate.

Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before choosing one.

- A I agree almost entirely with Brandon.
- B Although I agree more with Brandon, I think Jamal makes some good points.
- C I agree (or disagree) equally with Brandon and Jamal.
- D Although I agree more with Jamal, I think Brandon makes some good points.
- E I agree almost entirely with Jamal.

23. In lectures and textbooks, you often see examples of physics concepts applied to real-life situations. For example, many textbooks describe aeroplanes flying in crosswinds and explain the resultant motion of the aeroplane using vectors.

When you study for a test, which of the following best describes your attitude towards understanding real-life applications of physics such as air navigation?

- A Since they're not really tested, they're not very important (worth under 5% of my study time).
 - B They are a little important, but not nearly as important as certain other things – such as problem-solving techniques or the qualitative concepts (worth between 5% and 10% of my study time).
 - C The examples are fairly important (worth 10% to 20% of my study time).
 - D The examples are quite important (worth 20% to 30% of my study time).
 - E The examples are very important (worth 30% to 40% of my study time).
 - F The real-life examples are essential (worth over 40% of my study time).
24. Consider the following question from a physics textbook:

"A horse is urged to pull a cart. The horse refuses to try, stating Newton's 3rd law as a reason: The pull of the horse on the cart is equal but opposite to the pull of the cart on the horse. 'If I can never exert a greater force on the cart than it exerts on me, how can I ever start the cart moving?' asks the horse. How would you reply?"

When studying for a test, which of the following best describes your attitude towards studying and answering questions such as this one?

Studying these kinds of questions...

- A isn't helpful, because they aren't really what's tested.
- B helps a little bit, but not nearly as much as studying other things (such as problem-solving techniques or formulae).
- C is fairly helpful (worth a fair amount of time).
- D is quite helpful (worth quite a lot of my time).
- E is extremely helpful (worth a whole lot of my study time).

Appendix C

Physics expectations survey Pre-instruction response sheet

PHYSICS QUESTIONNAIRE

- A Strongly Disagree
- B Disagree
- C Neutral
- D Agree
- E Strongly Agree

Name: _____

Course Code: _____

Year: _____ Semester: _____

- | | | | | | | | | | | | | |
|-----|---|---|---|---|---|-----|---|---|---|---|---|---|
| 1. | A | B | C | D | E | 13. | A | B | C | D | E | |
| 2. | A | B | C | D | E | 14. | A | B | C | D | E | |
| 3. | A | B | C | D | E | 15. | A | B | C | D | E | |
| 4. | A | B | C | D | E | 16. | A | B | C | D | E | |
| 5. | A | B | C | D | E | 17. | A | B | C | D | E | |
| 6. | A | B | C | D | E | 18. | A | B | C | D | E | |
| 7. | A | B | C | D | E | 19. | A | B | C | D | E | |
| 8. | A | B | C | D | E | 20. | A | B | C | D | E | |
| 9. | A | B | C | D | E | 21. | A | B | C | D | E | |
| 10. | A | B | C | D | E | 22. | A | B | C | D | E | |
| 11. | A | B | C | D | E | 23. | A | B | C | D | E | F |
| 12. | A | B | C | D | E | 24. | A | B | C | D | E | |

25. Many students report that they sometimes come away from a lecture feeling like they understand a given topic or concept, but when they try to complete a homework problem on that topic, or a question in a test, they get stuck. Why do you think this happens?

What, do you think, could be done (by students and/or the lecturer) to "fix" this?

PHYSICS 1 FEEDBACK

What are three things you learned from this course? Explain briefly.

Name: _____

Course Code: _____

Year: _____ Semester: _____



- 1. A B C D E 11. A B C D E
- 2. A B C D E 12. A B C D E
- 3. A B C D E 13. A B C D E
- 4. A B C D E 14. A B C D E
- 5. A B C D E 15. A B C D E
- 6. A B C D E 16. A B C D E
- 7. A B C D E 17. A B C D E
- 8. A B C D E 18. A B C D E
- 9. A B C D E 19. A B C D E
- 10. A B C D E 20. A B C D E

- 21. A B C D E




To you, what does it mean to "understand" a formula, as opposed to "being familiar" with it?

- 22. A B C D E
- 23. A B C D E F

Please explain why an understanding of real-life examples is helpful, or not so helpful, for doing well in tests.

- 24. A B C D E

Many students report that they sometimes come away from a lecture feeling like they understand a given topic or concept, but when they try to complete a homework problem on that topic, or a question in a test, they get stuck. Why do you think this happens?

Motion Maps 1a		Name: _____	Crs: _____	Date: _____
Construct a motion map for:		Corrections / Notes		
1.	<p>a ship sailing south at constant speed.</p> 			
2.	<p>a car moving to the left at increasing speed.</p> 			
3.	<p>a ball rolling up a slope at decreasing speed.</p> 			

Motion Maps 1b

Construct a motion map for:

Corrections / Notes

4. a rocket whose burning fuel causes it to move vertically upwards at increasing speed.

5. a bullet fired vertically upwards (from when it leaves the gun).
[You will need to draw two maps, one for each part of its trajectory.]

Motion Maps 2a

Name: _____ Crs: _____ Date: _____

Corrections / Notes

1. The adjacent motion map represents the motion of a car. Determine the sign (-, 0, or +) of the position, velocity and acceleration of the car at position P.

Position: - 0 + Velocity: - 0 + Acceleration: - 0 +
 Explain: Explain:

2. The adjacent motion map represents the motion of a tennis ball. Determine the sign (-, 0, or +) of the position, velocity and acceleration of the ball at each of the positions 2 and 6. Determine also the signs of the displacement and the change in velocity as the ball moves from position 2 to position 6.

Position 2: - 0 + Velocity 2: - 0 + Acceleration 2: - 0 +
 Position 6: - 0 + Velocity 6: - 0 + Acceleration 6: - 0 +
 Displacement 2 → 6: - 0 + Change in velocity 2 → 6: - 0 +

Motion Maps 2b

	Corrections / Notes
<p>3. The adjacent motion map represents the motion of a cricket ball. Determine the sign (-, 0, or +) of the position, velocity and acceleration of the ball at each of the positions 4 and 5. Determine also the signs of the displacement and the change in velocity as the ball moves from position 4 to position 5.</p> <p>Position 4: - 0 +</p> <p>Position 5: - 0 +</p> <p>Velocity 4: - 0 +</p> <p>Velocity 5: - 0 +</p> <p>Acceleration 4: - 0 +</p> <p>Acceleration 5: - 0 +</p> <p>Displacement 4 → 5: - 0 +</p> <p>Change in velocity 4 → 5: - 0 +</p>	

The lecturer ...

1. was available for consultation at reasonable times outside of the lecturing times.
2. encouraged students to express themselves freely and openly on the subject matter.
3. set tests which focussed not only on memory work.
4. pointed out the importance and significance of the subject matter to the students.
5. presented the subject matter in an interesting way.
6. indicated clearly how each topic fitted in with the subject.
7. set test questions which were clearly formulated and relevant.
8. set test questions which emphasised the application of the theory.
9. gave interesting, relevant tutorials/assignments/projects.
10. conducted meaningful laboratory/practical work.
11. formulated clear study aims.
12. indicated the relationship between theory and practice.
13. stimulated original and independent thought.
14. consistently ascertained whether students understood and mastered the subject matter.
15. discussed tests with the students so as to enable them to find out why they made mistakes.
16. handed out notes which provided adequate coverage of the course.
17. presented the subject matter enthusiastically.
18. came well-prepared to lectures.
19. spoke clearly and with the necessary intonation.
20. showed interest in the students and their academic progress.
21. displayed a sense of humour.

22. used appropriate teaching media effectively (chalkboard, overhead projector, etc.)
23. was in control and maintained a reasonable level of discipline.
24. marked tests/assignments promptly.
25. was punctual for lectures and appointments.
26. used appropriate and relevant teaching methods effectively.
27. explained new concepts and ideas clearly.
28. was up-to-date with new developments in the subject field.
29. made effective use of lecturing time.
30. had the ability to communicate effectively in the language in which the subject was presented.
31. had a good perception of the student-lecturer relationship at a tertiary level.

The classrooms/laboratories ...

32. used by this lecturer provided a suitable learning/teaching environment.

The group work sessions ...

33. were enjoyable.
34. were effective in developing interpersonal skills.
35. helped the students master the subject matter.

General impression of the lecturer ...

36. On the basis of the detailed answers above you are asked to make a **GENERAL ASSESSMENT** of the lecturer (on the ANSWER sheet): As a lecturer he/she is

Excellent A B C D E Very poor

STUDENT FEEDBACK

This feedback will be used by the lecturer. If you wish to ensure aonymity it is suggested that you print your comments.

Lecturer's name: _____
 Subject: _____
 Date: _____

SECTION 1

Ring the letter of your choice.

A = Always
 B = Usually
 C = Sometimes
 D = Rarely
 E = Never

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
21. A B C D E
22. A B C D E
23. A B C D E
24. A B C D E
25. A B C D E
26. A B C D E
27. A B C D E
28. A B C D E
29. A B C D E
30. A B C D E
31. A B C D E
32. A B C D E
33. A B C D E
34. A B C D E
35. A B C D E
36. A B C D E

SECTION 2

1. List those aspects you liked about the SUBJECT:

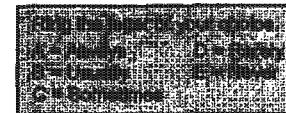
2. List those aspects you liked about the LECTURER:

3. List those aspects you disliked about the SUBJECT:

4. List those aspects you disliked about the LECTURER:

(AFRIKAANS OP KEERSY)

PHYSICS 1 FEEDBACK



8 am tutorials (Tues & Thurs)

The sessions...

- | | |
|--|-----------|
| 1. were attended by me. | A B C D E |
| 2. helped me to better understand the Physics material. | A B C D E |
| 3. helped me complete the Weekly Problem Sets. | A B C D E |
| 4. provided me with an opportunity to work on Physics in groups with other students. | A B C D E |

Other comments/suggestions:

The peer tutors...

- | | |
|---|-----------|
| 5. were punctual and present at all times. | A B C D E |
| 6. had a good grasp of the subject material. | A B C D E |
| 7. explained things clearly. | A B C D E |
| 8. provided correct answers to tutorial questions. | A B C D E |
| 9. played an important role in improving my performance in Physics. | A B C D E |

Other comments/suggestions:

WPS intervention

The Weekly Problem Sets...

- | | |
|---|-----------|
| 10. provided an <i>enjoyable</i> challenge. | A B C D E |
| 11. encouraged me to think more deeply about Physics. | A B C D E |
| 12. contained interesting, relevant questions. | A B C D E |
| 13. promoted effective groupwork. | A B C D E |
| 14. helped to improve my test marks. | A B C D E |
| 15. caused me an unreasonable amount of stress. | A B C D E |

Other comments/suggestions: PTO

The WPS Mentor/Tutor (Mr Makupula)...

- | | |
|--|-----------|
| 16. was available for consultation at reasonable times. | A B C D E |
| 17. had a good grasp of the subject material. | A B C D E |
| 18. explained things clearly. | A B C D E |
| 19. gave feedback on Tuesday mornings which was useful/helpful to me. | A B C D E |
| 20. had the ability to communicate effectively in the language we used together. | A B C D E |
| 21. showed interest in students and their academic progress. | A B C D E |
| 22. played an important role in improving my performance in Physics. | A B C D E |

Other comments/suggestions: PTO

In your opinion, should the present system of Weekly Problem Sets for Physics 1 continue?

Yes	No
-----	----

P0311

SEMESTER 1 2004

PHYSICS 1 TEST 1

Marks: 60
Time: 70

Question 1

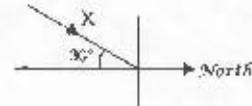
- Choose that answer which in your opinion is the correct or best answer and mark the appropriate block on the answer sheet provided.
- If you are *sure* of your answer, mark also the block containing the question mark.
- If you make a cross in the box containing the word NAME you will be awarded 4 bonus marks.
- Use only a PENCIL on your answer sheet.
- In the case of a wrong answer erase the pencil mark completely.

1.1 Which of the following is equivalent to 900 cm^2 ?

- A $0,09 \text{ m}^2$ B $0,3 \text{ m}^2$ C $0,9 \text{ m}^2$ D $9 \times 10^3 \text{ mm}^2$

1.2 The bearing of vector X in the adjacent rough sketch is

- A 30° B 60°
C 120° D 210°



1.3 The resultant of two displacement vectors, 4 km SW and 5 km SE, is

- A 3 km, S B 3 km, 174° C 6,4 km, 174° D 6,4 km, 186°

Questions 1.4 and 1.5 refer to an athlete who runs clockwise around a circular track with a radius of 70 m. Starting in the west, he takes a minute to reach the south.



1.4 His average speed for the three-quarter circuit, in m/s, is

- A 1,2 B 1,7 C 5,5 D 7,3

1.5 His average velocity for the three-quarter circuit is

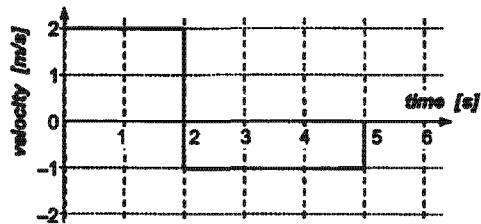
- A 1,7 m/s, SE
B 1,7 m/s, NW
C 5,5 m/s, SE
D 5,5 m/s, NW

1.6 Two forces of 6 N and 8 N, with an angle of 120° between them, act on the same point. The magnitude of their resultant is

- A less than 10 N
B 10 N
C between 10 N and 14 N
D 14 N

- 1.7 The motion of an object in a straight line is illustrated on the adjacent velocity-time graph.

The magnitude of its average velocity over the 5 s interval is



- A 0 m/s B 0,2 m/s C 0,5 m/s D 1,4 m/s

$$7 \times 4 = \boxed{28}$$

Question 2

- 2.1 A pilot wishes to fly 100 km due south. There is an easterly crosswind blowing at 65 km/h. Calculate:
- 2.1.1 the direction in which the pilot must fly if the plane's normal air speed is 500 km/h; (5)
- 2.1.2 how long the flight will take. (5) [10]
- 2.2 A man travels 10 km north at 30 km/h before turning and travelling 10 km south at 40 km/h. Calculate:
- 2.2.1 his average speed for the whole trip; (7)
- 2.2.2 his average velocity for the whole trip; (2) [9]
- 2.3 A car slows down uniformly from 70 km/h to 30 km/h in 12 s. Calculate the distance it travels during this interval. [8]
- 2.4 Two trolleys are 4 m apart on a long inclined plane at time $t = 0$, as shown. Trolley A is moving down the slope at a constant speed of 3 m/s, while trolley B is just starting from rest, accelerating at 2 m/s^2 . Determine how far trolley B travels before it catches up with trolley A. [10]



$$\boxed{37}$$

END

P9312

SEMESTER 1 2004

PHYSICS

TEST 2

Marks: 80

Time: 45



Question 1

- Choose that answer which in your opinion is the correct or best answer and mark the appropriate block on the answer sheet provided.
- If you are sure of your answer, mark also the block containing the question mark.
- Use only a PENCIL on your answer sheet.
- In the case of a wrong answer erase the pencil mark completely.

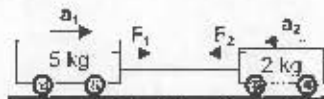
1.1 If the velocity of a motor car is halved, which of the following will also be halved?
 A inertia B momentum C acceleration D kinetic energy

1.2 A trolley with a mass of 2 kg moves along a frictionless horizontal surface at a speed of 0,6 m/s. A stationary 4 kg object is dropped onto the moving trolley. The trolley's new speed is

- A 0,1 m/s B 0,2 m/s C 0,3 m/s D 0,4 m/s

1.3 Two trolleys, masses 5 kg and 2 kg, are joined by a rubber band and held apart as shown. F_1 and F_2 represent the respective forces exerted by the rubber band on each trolley, while a_1 and a_2 represent the respective accelerations of the trolleys when they are released. Which of the following is correct regarding the relative magnitudes of the forces and the accelerations?

- A $F_1 > F_2$ and $a_1 < a_2$
 B $F_1 < F_2$ and $a_1 < a_2$
 C $F_1 = F_2$ and $a_1 < a_2$
 D $F_1 = F_2$ and $a_1 = a_2$



1.4 Two forces of 5 N each act at the same point. The magnitude of their resultant is 5 N. Which of the following statements is true?

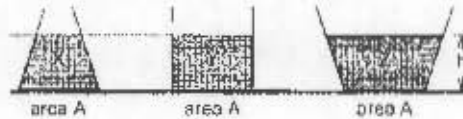
- A The angle between the forces is 60° .
 B The angle between the forces is 120° .
 C The forces are opposite in direction.
 D The forces are perpendicular to each other.

1.5 The sketch shows a picture hanging on a nail. For the tension in the hanging wire to equal the weight of the picture, it should be

- A 30° B 45°
 C 60° D 90°



- 1.6 Each of the vessels shown is filled to a depth h with a liquid of density ρ . The downward force of the liquid on the base



- A is greatest in vessel X
 B is greatest in vessel Y
 C is greatest in vessel Z
 D is the same in all three vessels

- 1.7 A foam block is 5 mm high. It floats on water with a draught of 1 mm, as shown. The relative density of the foam is

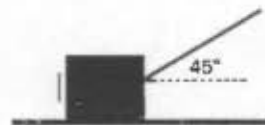


- A 0,1 B 0,2
 C 0,4 D 0,8

$7 \times 4 = [28]$

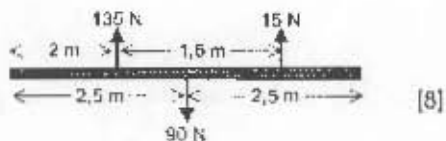
Question 2

- 2.1 A 170 kg crate is dragged 20 m across a level floor at a constant speed of 0,5 m/s by means of a rope. A constant force of 283 N is applied to the rope, which makes an angle of 45° with the horizontal. Calculate:



- 2.1.1 the frictional force on the crate; (4)
 2.1.2 the work done on the crate in moving it 20 m; (4)
 2.1.3 the magnitude of the normal force on the crate; (4)
 2.1.4 the coefficient of kinetic friction for the surfaces involved; (3)
 2.1.5 how long it takes to drag the crate 20 m; (2)
 2.1.6 the force required on the rope to keep the crate moving at 0,25 m/s if the rope now makes an angle of only 30° with the horizontal. (5) [22]

- 2.2 Determine the magnitude and position of the single force required to balance the plank in the adjacent sketch.



- 2.3 A tennis ball with a diameter of 70 mm and an overall relative density of 0,28 floats in water. Calculate
- 2.3.1 the mass of the ball; (6)
 2.3.2 the mass of water the ball displaces; (2)
 2.3.3 the volume of water the ball displaces. (2) [10]

[40]

SUBJECT: VAK:	PHYSICS 1 FISIKA 1	CODE/KODE:	PHB113C PHB11LC
ANNEXURES/BYLAE: PAGES/BLADSYE:	2 8	TIME/TYD: DATE/DATUM:	0900 – 1200 03/06/2003



CAPE TECHNIKON

FACULTY: APPLIED SCIENCES
FAKULTEIT: TOEGEPASTE WETENSKAPPE

COURSE: ND ANALYTICAL CHEMISTRY ND CHEMICAL ENGINEERING ND FOOD TECHNOLOGY ND BIOMEDICAL TECHNOLOGY ND OCEANOGRAPHY	KURSUS: ND ANALITIESE CHEMIE ND CHEMIESE INGENIEURSWESE ND VOEDSELTEGNOLOGIE ND BIOMEDIESE TEGNOLOGIE ND OSEANOGRAFIE
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EXAMINER/EKSAMINATOR:	G LEIGH
MODERATORS:	M SMITH / V ELLIOTT

INSTRUCTIONS: 1. Answer ALL the questions. 2. Full marks = 210. [Marks available = 223.] 3. Number each subsection of each question fully and clearly. 4. Consult the data booklet where necessary. DO NOT MARK THE BOOKLET IN ANY WAY – AND RETURN IT INSIDE YOUR SCRIPT. 5. Calculators may be used, but take care not to print working lines from your answers.	INSTRUKSIES: 1. Beantwoord ALLE vrae. 2. Volpunte = 210. [Punte beskikbaar = 223.] 3. Nummer elke onderafdeling van elke vraag volledig en duidelik. 4. Raadpleeg die gegewensboekie waar nodig. MOET NIE ENIGE MERKE OP HIERDIE BOEKIE MAAK NIE – EN HANDIG DIT BINNE U ANTWOORDSTEL IN. 5. Sakrekenaars mag gebruik word, maar maak seker dat daar nie enige berekeningstappe van jou antwoorde weggelaat word nie.
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DO NOT TURN THIS PAGE OVER BEFORE THE STARTING TIME
MOENIE omlaag slaai voor die aanvangstyd

Question 1

- Choose that answer which in your opinion is the correct or best answer and mark the appropriate block on the answer sheet provided.
- If you are *sure* of your answer, mark also the block containing the question mark.
- Use only a PENCIL on your answer sheet.
- In the case of a wrong answer erase the pencil mark completely.

1.1 Which of the following is equivalent to a litre?

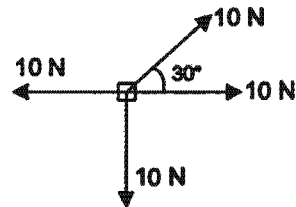
- A $0,001 \text{ m}^3$ B $0,01 \text{ m}^3$ C $0,1 \text{ m}^3$ D 1 dm^3

1.2 In which of the following pairs are *both* physical quantities vectors?

- A mass and momentum
 B mass and acceleration
 C acceleration and momentum
 D kinetic energy and momentum

1.3 The magnitude of the resultant force in the adjacent diagram is

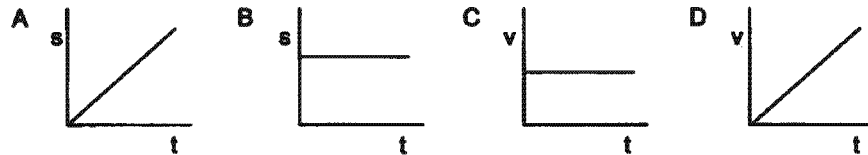
- A 0 N
 B 10 N
 C greater than 10 N
 D smaller than 10 N, but greater than 0 N



1.4 An athlete runs three quarters of the way around a circular track in one minute. The track has a radius of 70 m. The magnitude of his average *velocity*, in m/s, is

- A 1,2 B 1,7 C 3,5 D 5,5

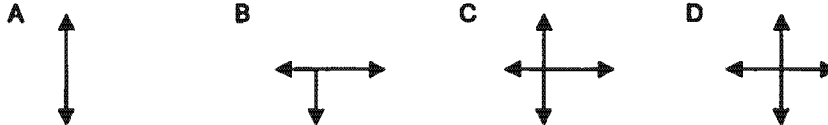
1.5 Which graph represents BOTH zero velocity AND zero acceleration?



1.6 A 3 kg ball strikes a wall at 6 m/s and bounces straight back at 4 m/s. The change in momentum, in kg.m/s, is

- A -6 B 6 C 12 D 30

- 1.7 A car moves along a horizontal road to the right at a constant velocity of 80 km/h. Which of the following diagrams best represents the forces acting on the car?

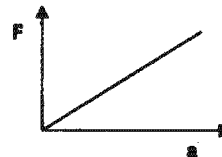


- 1.8 Two iron spheres of mass 1 kg and 2 kg respectively are dropped simultaneously from a building in the absence of air friction. When they are each 1 m above the ground, they have the same

- A inertia
B momentum
C acceleration
D potential energy relative to the ground

- 1.9 The graph shows the relationship between the acceleration a of a given mass and the force F used to produce that acceleration in a frictionless system. The gradient of the graph represents

- A mass
B displacement
C average velocity
D final velocity



- 1.10 The equilibrant of two forces acting at the same point on a body

- A prevents the body from moving
B is exactly the same as the resultant
C has the opposite effect to the two forces together
D is that single force which has the same effect as the other two forces together

- 1.11 A picture with a weight W is hung on a nail on a wall by means of a cord at the back of the picture, as shown.



The tension in the cord is

- A W B $\frac{W}{2 \sin 15^\circ}$ C $\frac{W}{\sin 15^\circ}$ D $\frac{W}{\sin 30^\circ}$

- 1.12 A 4 N block is suspended by a string from one end of a stick. If the stick is balanced by a support one quarter of its length away from the block, the stick's weight is

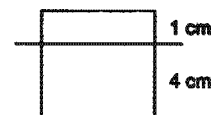


- A 1 N B 2 N C 4 N D 8 N

- 1.13 The upthrust on a body immersed in a fluid is equal to the

- A mass of fluid displaced
 B weight of fluid displaced
 C volume of fluid displaced
 D density of fluid displaced

- 1.14 A cube of wood has a side of 5 cm. It floats in water with 1 cm still showing above the surface, as shown. The relative density of the wood is



- A 0,2 B 0,4
 C 0,8 D 1,2

- 1.15 A block of wood measures 20 cm by 5 cm by 3 cm. Each cubic centimetre of the wood has a mass of 0,85 g. The density of the wood is therefore

- A $\frac{0,85}{300} \text{ g/cm}^3$ B $(0,85 \times 300) \text{ g/cm}^3$ C $0,85 \text{ g/cm}^3$ D 850 g/cm^3

- 1.16 The phase equilibrium $\text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{O}(g)$ will be reached in a closed container

- A at the triple point of water
 B as soon as the water begins to boil
 C once the rates of evaporation and condensation are equal
 D when the saturated vapour pressure equals the external pressure

- 1.17 During melting, lead experiences NO change in

- A phase
 B volume
 C temperature
 D the internal energy of its particles

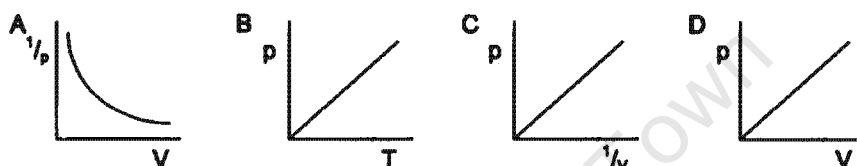
- 1.18 A change of $x \text{ }^\circ\text{C}$ is exactly the same as a change of

- A $(273,15 + x) \text{ K}$ B $(273,16 + x) \text{ K}$ C $(x - 273) \text{ K}$ D $x \text{ K}$

1.19 Water at 0°C

- A will freeze by itself
- B is less dense than ice at 0°C
- C needs extra energy in order to freeze
- D contains more energy than the same mass of ice at 0°C

1.20 Which one of the following sketch graphs best represents Boyle's law?



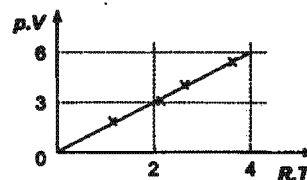
1.21 Steam does not obey Boyle's law because

- A it is too hot
- B it is actually a liquid
- C it is a vapour, not a gas
- D it does not have a fixed mass

1.22 Which of the following temperature increases would cause the pressure of an enclosed gas to double?

- A 0°C to 100°C
- B 50°C to 100°C
- C 323 K to 373 K
- D 320 K to 640 K

1.23 A balloon is inflated with air and then subjected to various temperatures and pressures. The adjacent graph of the product $p \cdot V$ plotted against the product $R \cdot T$ (in standard SI units) illustrates the results.



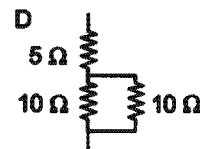
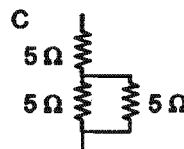
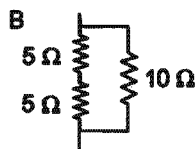
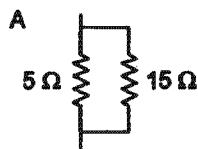
The number of moles of air in the balloon is

- A $\frac{2}{3}$
- B 1,5
- C 4
- D 6

1.24 When two charges are 1 m apart, the electrostatic force between them is F newtons. If the charges are moved so that they are now 2 m apart, the electrostatic force between them becomes

- A $\frac{1}{4}F$
- B $\frac{1}{2}F$
- C $2F$
- D $4F$

1.25 Which of the following arrangements provides an effective resistance of $10\ \Omega$?



1.26 An electric light bulb is labelled $12\ \text{V}; 2\ \text{A}$. When operating correctly

- A its resistance is $24\ \Omega$
- B the power of the bulb is $6\ \text{W}$
- C it should draw more than $6\ \text{A}$
- D it consumes $120\ \text{J}$ of energy every 5 seconds

1.27 If $1\ \text{J}$ of work is done in moving a charge of $1\ \text{C}$ from point X to point Y in an electric field,

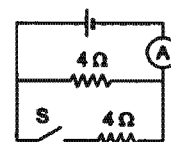
- A the current between X and Y is $1\ \text{A}$
- B the resistance between X and Y is $1\ \Omega$
- C the potential difference between X and Y is $1\ \text{V}$
- D the magnitude of the force exerted on the charge is $1\ \text{N}$

1.28 The $\text{kW}\cdot\text{h}$ is a unit of

- A energy
- B power
- C time
- D electricity

1.29 The resistances of the battery and ammeter in the given circuit are negligible. When switch S is closed, the reading on the ammeter

- A drops to zero
- B is halved
- C is doubled
- D increases slightly



1.30 A $60\ \text{W}$ bulb and a $100\ \text{W}$ bulb are connected in series to the mains. Which statement is correct regarding the brightness of the bulbs?

- A The $60\ \text{W}$ bulb burns brighter.
- B The $100\ \text{W}$ bulb burns brighter.
- C Both bulbs burn equally brightly.
- D The bulb connected first in the circuit burns brighter.

30 x 3 = 90

Question 2

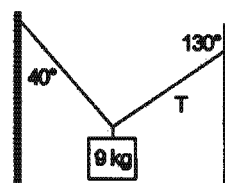
- 2.1 A truck's speed increases uniformly from 4 m/s to 16 m/s in 20 s.
Calculate:
- 2.1.1 the magnitude of the truck's acceleration; (4)
- 2.1.2 the distance travelled by the truck during the 20 s; (4)
- 2.1.3 the truck's average speed during the 20 s. (2) [10]

- 2.2 In the same instant that a Porsche races past him at 129,6 km/h, a speed cop sets off on his motorcycle, accelerating uniformly at 8 m/s^2 , to catch the speedster. After 5 s the traffic officer reaches his top speed, which he then maintains until he catches up to the car.
- 2.2.1 Calculate the motorbike's top speed. (4)
- 2.2.2 Draw the complete Physics diagram of the situation which you would use to determine how long it takes (after the car passes him) before the traffic officer catches up to the car. Your diagram should include all the relevant variables which you know, as well as those which you would need to determine in order to find your answer. (7) [11]

- 2.3 A 9 kg mass hangs suspended between two supports as shown.

- 2.3.1 State the Triangle rule for forces in equilibrium. (3)

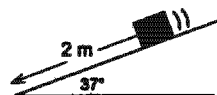
- 2.3.2 Calculate the tension, T , in the right hand string. (5) [8]



[29]

Question 3

- 3.1 A box slides down a slope which makes an angle of 37° with the horizontal, as shown in the sketch. When it is 2 m from the bottom it is travelling at 1 m/s. The coefficient of friction involved is 0,5.



- 3.1.1 Show that the box is accelerating at 2 m/s^2 . (10)
- 3.1.2 Calculate how long the box takes to slide the last 2 m. (5) [15]

- 3.2 The 2 m-long rigid bar in the sketch has a mass of 30 kg. It is being pulled upwards at one end by a 50 N force. Calculate:



- 3.2.1 the sum of the moments about X; (5)
- 3.2.2 the position and magnitude of the force required to keep the bar in equilibrium. (5) [10]
- 3.3 A 20 g gold ring hangs from a spring balance. What is the reading on the spring balance when the ring is completely submerged in water? [5]

[30]

Question 4

- 4.1 A steel plate at a temperature of 20°C is 3,005 mm thick. To what temperature must it be cooled for it to fit into a slot which is exactly 3 mm wide? [5]
- 4.2 State three factors which will *increase* the rate of evaporation of a liquid. [6]
- 4.3 Calculate the quantity of heat conducted through 10 m² of a 24 cm-thick brick wall in 30 minutes. The inside temperature of the wall is 30°C; the outside is at 10°C. [4]
- 4.4 A copper calorimeter with a heat capacity of 70 J/K contains 50 ml of water and 30 g of ice at 0°C. Steam at 100°C is bubbled through the water until the final temperature of the calorimeter and its contents is 25°C. Calculate the mass of steam which condenses. [6]
- 4.5 Use the equation $p.V = n.R.T$ to *calculate* the molar volume of oxygen at STP. [4]

[25]

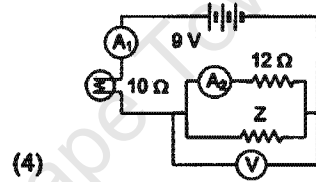
Question 5

5.1 An electron and a proton enter the electric field between two oppositely charged parallel plates with the same initial velocity, parallel to the plates as shown.



- 5.1.1 Define "electric field". (2)
- 5.1.2 Redraw the diagram and sketch in the paths the two particles will follow. (4) [6]

5.2 The 9 V battery in the adjacent circuit has negligible internal resistance. Ammeter A_1 reads 0,5 A. Calculate:



- 5.2.1 the potential difference across the bulb; (4)
- 5.2.2 the reading on:
 - (a) the voltmeter; (2)
 - (b) ammeter A_2 ; (3)
- 5.2.3 the resistance of Z; (4)
- 5.2.4 the power of the bulb. (4) [17]

5.3 While buying a kettle, you have to choose between two models. Kettle X is rated at 2 kW, while kettle Y is rated at 3 kW. The kettle you buy will be plugged into the 220 V mains and used to bring 1 071 ml of water at 20°C to the boil. The electricity tariff is currently 35c a kW.h. Assuming that each kettle is 100% efficient, compare the two kettles in terms of...

- 5.3.1 the cost of boiling the water; (6)
- 5.3.2 the time taken to boil the water. (6) [12]

35

END

References

- Alesandrini, K.L. (1981). Pictorial-verbal and analytic-holistic learning strategies in science learning. *Journal of Educational Psychology*, 73, 358-368.
- Archer, A., Frith, V. & Prince, R.N. (2002). A Project-based approach to numeracy practices at university focusing on HIV/AIDS. *Literacy and Numeracy Studies*, 11 (2), 123-131.
- Aristotle. *Metaphysics, Book 1*.
- Buffler, A. & Allie, S. (1993). Towards an active learning environment in physics: developing problem solving skills through cooperative learning. In Boughey, C. & Leibowitz, B. (Eds.), *Proceedings of the Annual Conference of the South African Association of Academic Development* (pp. 15-29).
- Burden, P. & McAvinia, C. (1998). Report: Employers' Needs and Graduate Skills. Centre for Learning Developments, University of Surrey.
- Cliff, A.F., Yeld, N. & Hanslo, M. (2003). Assessing the academic literacy skills of entry-level students, using the Placement Test in English for Educational Purposes (PTEEP). Paper presented at the 10th Bi-annual Conference of the European Association for Research in Learning and Instruction, Padova, Italy, August 2003.
- Department of Education (1997). Education Policy document: "General Policy for Technikon Instructional Programmes" – Report 150 (97/01), paragraph 2.1.1.

- Dufresne, R.J., Leonard, W.J. & Gerace, W.J. (1992). Research-based materials for developing a conceptual approach to problem solving in science. In Grayson, D. (Ed.), *Proceedings of the Workshop held on Research in Science and Mathematics Education, Cathedral Peak, South Africa* (pp. 93-103).
- Dufresne, R.J., Leonard, W.J. & Gerace, W.J. (1993). An approach to promoting conceptual understanding of physics through problem-solving activities. Workshop. University of Massachusetts.
- Elby, A., (2001). Helping physics students learn how to learn. *Physics Education Research, American Journal of Physics Supplement*, 69, S54-S64.
- Fox, R. & Radloff, A. (1996). We're working hard but are we working smart? Some ideas to "unstuff" the curriculum. *Different Approaches: Theory and Practice in Higher Education*. Proceedings HERDSA Conference 1996. Perth, Western Australia, 8-12 July. <http://www.herdsa.org.au/confs/1996/fox.html>.
- Frith, V., Bowie, L., Gray, C. & Prince, R.N. (2003a). Mathematical literacy of students entering first year at a South African university. In Jaffer, S. & Burgess, L. (Eds.), *Proceedings of the Ninth National Congress of the Association for Mathematical Education of South Africa* (pp. 186-193).
- Frith, V., Gray, C., Jaftha, J. & Prince, R.N. (2003b). Report: Numeracy competency of some applied science students at the Cape Technikon in 2003.
- Fuller, R.G. (1982). Solving physics problems – how do we do it? *Physics Today*, September 1982, 43-47.
- Gerace, W.J. (2001). Problem solving and conceptual understanding. In Franklin, S., Marx, J. & Cummings, K. (Eds.), *Proceedings of the 2001 Physics Education Research Conference, Rochester* (pp. 33-36).
- Gerace, W.J., Mestre, J.P., Dufresne, R.J. & Leonard, W.J. (1992). *Materials for developing concept-based problem-solving skills in physics*. University of Massachusetts.
- Heller, K., Heller, P. & Hollabaugh, M. (1994). *Cooperative Group Problem Solving in Physics*. University of Minnesota.

- Heller, K. & Heller, P. (1999). *Minnesota Model for Large Introductory Courses*. University of Minnesota.
- Heller, P. & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, 60, 637-644.
- Heller, P., Keith, R. & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics*, 60, 627-636.
- Hewitt, P.G. (1983). Millikan Lecture 1982: The missing essential – a conceptual understanding of physics. *American Journal of Physics*, 51, 305-311.
- Hewitt, P.G. (2002). *Conceptual Physics* (9th ed.). San Francisco: Addison Wesley.
- Hobden, P. (2002). Reclaiming the meaning of problem solving: the need for a common understanding of the terms problem and problem solving. In Malcolm, C. & Lubisi, C. (Eds.), *Proceedings of the 10th Annual Meeting of the Southern African Association for Research in Mathematics and Science Education* (pp. 98-104).
- Hortin, J. (1994). Theoretical foundations of visual learning. In Moore, D. & Dwyer, F. (Eds.), *Visual Literacy: A Spectrum of Visual Learning* (pp. 5-29). Englewood Cliffs NJ: Educational Technology Publications.
- Kurfiss, J.G. (1988). *Critical thinking: theory, research, practice and possibilities*. ASHE-ERIC Higher Education Report No. 2. Washington, D.C.: The George Washington University, Graduate School of Education and Human Development.
- Larkin, J.H., McDermott, J., Simon, D.P. & Simon, H.A. (1980). Expert and novice performance in solving physics problems. *Science*, 208, 1335-1342.
- Lawson, A.E. (1978). The development and validation of a classroom test of formal reasoning. *Journal of Research in Science Teaching*, 15(1), 11-24.
- Lawson, A.E. (1987). *Classroom Test of Scientific Reasoning: revised pencil and paper version*. Tempe: Arizona State University.

- Lawson, A.E. (1992). What do tests of “formal” reasoning actually measure? *Journal of Research in Science Teaching*, 29(9), 966-983.
- Linder, C.J. & Hillhouse, G. (1996). Teaching by conceptual exploration. *The Physics Teacher*, 34, 332-338.
- Lord, T.R. (1984). A plea for right brain usage. *Journal of College Science Teaching*, 14, 100-102.
- May, D.B. & Etkina, E. (2002). College physics students’ epistemological self-reflection and its relationship to conceptual learning. *American Journal of Physics*, 70, 1249-1258.
- Mazur, E. (1997). *Peer Instruction: A User’s Manual*. Upper Saddle River: Prentice Hall.
- Meltzer, D.E. (2002). The relationship between mathematics preparation and conceptual learning gains in physics: a possible “hidden variable” in diagnostic pretest scores. *American Journal of Physics*, 70, 1259-1268.
- Mpuru, S. (2003). House Father of Groote Schuur Residence, Cape Technikon. Private communication.
- Numeracy Centre website (October 2003): <http://www.numeracy.uct.ac.za>.
- Pastoll, G (2002). *Motivating People to Learn*. Cape Town: The Novalis Press.
- Redish, E.F. (2003). *Teaching Physics with the Physics Suite*. Wiley.
- Redish, E.F., Steinberg, R.N. & Saul, J.M. (1998). Student expectations in introductory physics. *American Journal of Physics*, 66, 212-224.
- Reif, F., Larkin, J.H. & Brackett, G.C. (1976). Teaching general learning and problem solving skills. *American Journal of Physics*, 44, 212-217.
- Reif, F. (1986). Scientific approaches to science education. *Physics Today*, November 1986, 48-54.
- Reif, F. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought processes. *American Journal of Physics*, 63, 17-32.

- Terenzini, P., Springer, L., Yeager, P., Pascarella, E. & Nora, A. (1996). First-generation college students: Characteristics, experiences, and cognitive development. *Research in Higher Education*, 37, 1-22.
- Tobias, S. (1990). *They're Not Dumb, They're Different: Stalking the Second Tier*. Tucson: Research Corporation.
- Van Heuvelen, A. (1990). *Overview, Case Study Physics: Physics Study Guide I*. New Mexico State University.
- Van Heuvelen, A. (1991a). Learning to think like a physicist: A review of research-based instructional strategies. *American Journal of Physics*, 59, 891-897.
- Van Heuvelen, A. (1991b). Overview, case study physics. *American Journal of Physics*, 59, 898-907.
- Van Heuvelen, A. (2001). Millikan Lecture 1999: The workplace, student minds, and physics learning systems. *American Journal of Physics*, 69, 1139-1146.
- Victoria University of Wellington (2003). Student Services Group: Career Development and Employment, Employment Skills Survey, October 2003.
- Wilson, V. (2000). *Can thinking skills be taught? A paper for discussion*. Paper presented at the Education Forum on Teaching Thinking Skills, Edinburgh.
- Zhang, L. (2002). Thinking styles and modes of thinking: implications for education and research. *The Journal of Psychology*, 136(3), 245-261.
- Zipin, L. & Brennan, M. (2001). 'Cultural capital' and the literacy needs of a new generation of pre-service teachers. Refereed paper delivered at Curriculum 2001 Conference: Education Futures and New Citizenships, 29 September - 1 October 2001, Canberra, Australian Capital Territory. http://acsainc.com.au/content/2001_cultural_capital.pdf