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ASSESSING BASIC PROCESS SKILLS IN PRACTICAL SCIENCE AND TECHNOLOGY USING SIMPLE MANUFACTURED OBJECTS

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This article describes the development, validation, classification, administration and assessment of a compact programme of ten core practical task items chosen from a pool of 33 practical tasks in basic physical science and technology. The investigation focuses on test item formulation with an emphasis on assessing the process skills competence of students seeking admission to technikons and engineering faculties, especially when prospective engineering students have completed high school without having been participants in science practical work.

In South Africa, many students from impoverished and underprivileged backgrounds are completing schooling without ever attempting or even seeing a science demonstration, experiment or piece of apparatus at school. Many African students do not possess their own science textbooks. Therefore, the current compact programme of practical tasks may be utilised as a norm-referenced diagnostic kit by lecturers in science and engineering faculties of universities and in technikons who receive many English second language tertiary students. The activity stations may be used as probes of these students' understanding of what they might have studied earlier in books or on the chalkboard.

More than 80 adult engineering, science and technology teachers-in-training, experienced lecturers, academics and teachers were involved in the field trials of the compact programme as well as more than 300 science and technology students in schools.

The practical tasks were designed for diagnostic use with English second languagestudents, using manufactured items and products of technology such as a refrigerator bulb, different types of shoes, an ammeter, measuring cylinder, etc. The investigation reports that both English first and second language speakers achieved equally well with some manufactured objects, but unequally with other items of equipment.

Introduction

The policies of the Engineering Council of South Africa (ECSA) have changed to an outcomes-based accreditation framework progressively in the recent years. Furthermore, the introduction of the National Qualifications Framework requires outcomes-based standards to be developed for all the professions. In the past, education and training were mostly input- or teaching-based. The new frameworks now require a shift to an outcomes and learning-based system. In future, what skills and knowledge have been acquired and been used by students will be taken into account; not where a degree has been obtained.

In South Africa, Regan has described the development of these new criteria, and he laid out certain characteristics that engineering programmes must demonstrate [1]. These include:

- An ability to apply knowledge of mathematics, science and engineering.
- An ability to design and construct experiments, as well as to analyse and interpret data.
- An ability to identify, formulate and solve engineering problems.
- An ability to communicate effectively.
- A recognition of the need for, and an ability to engage in life-long learning.
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

However, in South Africa, these proficiencies and abilities remain under-developed in many English second language students in the zone of school/technikon-university transition, on account of impoverished home backgrounds and communities, especially in rural areas.

In Australia, Johnson laid out some strategies to draw more school students into the engineering profession [2]. These included the following:

- Setting up engineering-related networks in high schools for students and parents.
- Contributing to school curriculum committees and education boards.
- Reviewing the resources for, and positively influencing the teaching of mathematics, science and technology in primary and secondary schools so that students are better-prepared for, and are more predisposed towards science and engineering careers.

Johnson also argued that engineering is poorly understood in Australian schools, so primary and secondary schools were among sub-groups in the broader community that warrant attention [2]. He further argued that engineering simply did not exist for many young people. He reported that the main thrust in the ASTEC's report of 1996 was to provide young people with a general understanding of science and technology and the contributions they make to society.

He stated that the engineering profession and education needed to form partnerships at various levels with school-age students, teachers, schools and school systems. He mentioned the following points among the goals of these partnerships:

- Increase the number of school students wishing to pursue careers in engineering by:
- Alerting students to the breadth and scope of engineering education.
- Ensuring that the attractive features of engineering education courses are well known to school students.
- Ensure a high level of contribution by the engineering profession to debates on the curricula of schools, especially in the teaching of mathematics.

He pointed out that the most important changes should be those taking place in the courses themselves in order to make them more relevant to the needs of present day society. These suggestions for increasing links between the engineering profession and school have also been taken to heart in South Africa.

Background

One of the emergent trends predicted to impinge on developing countries during the 1990s was that technology would form a new focus of interest in the curriculum, with an increasing emphasis on the skills needed to solve real life problems [3]. As a result, technology has now taken its place in the new curriculum in South African Schools as one of eight learning areas.

Technology is an intrinsic part of a cultural and social system. It both shapes and reflects the values of that particular system. It is not only a matter of research, design and craft but also of economy, production, management, labour, marketing and maintenance.

Science for All Americans on-line pointed out that, as technologies become more sophisticated, their links to science become stronger [3]. Engineering is defined as the component of technology that is most closely allied to scientific inquiry and mathematical modeling. Scientists see patterns in phenomena as making the world understandable; engineers see them as making the world manipulable. Scientists try to show that their theories fit data; mathematicians seek to show logical proof of abstract connections; engineers seek to demonstrate that designs work. These statements imply that a school curriculum for science, mathematics and technology should provide a basis for these areas of study.

In South Africa, the recent Revised National Curriculum Statement defines technology as

> *The use of knowledge, skills and resources to meet people's needs and wants by developing practical solutions to problems, taking social and environmental factors into consideration [4].*

It was emphasized in the Report Summary of the Institution of Engineers in Australia in 1996 that there was very important work to be done at school level in order to draw more people into engineering profession and also to emphasize the role and importance of engineering [5]. The technology learning area of the 2002 Revised National Curriculum Statement of South Africa also aims to introduce learners to some aspects of the engineering profession, and to certain skills that an engineer is required to possess [6]. These include application and the design process, minimizing the negative impacts that solutions may have on the environment, opportunities to cooperate and interact with each other and also with their communities, managing technological resources, and so on. It also states that it combines knowing with doing by affording learners opportunities to apply and integrate their knowledge that they learn in other learning areas.

Both the Natural Sciences and Technology learning areas have three very closely linked outcomes in South Africa [6]. These are: the attainment of scientific and technological processes and skills; acquiring scientific and technological knowledge; and the interrelationships between science and technology and society.

Engineering is of salient importance in the economic development of a country. Schacht highlighted this, and stated that the engineering profession has a big part to play in implementing the Working Nation strategy of Australia [7]. By implication, engineering educators have an important role in helping the profession to achieve this objective.

Some aspects of engineering education should be involved at the school level. The Report Summary of the Institution of Engineers in Australia stated that there was a lack of understanding of engineering in the primary and secondary schools in 1996. The review also recommended greater contact with schools in various ways:

We conclude that there is more important work remaining to be done to provide engineering educators with and understanding of the attitudes, values and aspirations of high school students in the context of engineering as a possible career.

Importance of the problem

According to a United Nations report released in July 2001, the developing world was far behind developed countries in terms of human development. Of 4.6 billion people in the developing countries, more than 850 million were illiterate, nearly one billion lacked access to basic sanitation. The literacy rate was 55% in South Asia and 60% in sub-Saharan Africa – well below the 73% level for developed countries [8]. However, on a positive note, in the report South Africa was listed among 46 technological "hubs" in the world.

Technology is a tool for human development that enables people to increase their incomes, live longer and healthier, enjoy a better standard of living, participate more in their communities and lead more creative lives [8]. Like education, it enables people to lift themselves out of poverty. Therefore it is not just a reward of, but also a tool for, growth and development.

Despite a high level of enrolment of South African children in primary education (96%), only half of them have proceeded to high school. Only 18% of all tertiary level students are studying science, mathematics and engineering. Every country, no matter how poor, needs to build its own capacity to adapt and master global technologies and this means investing in secondary education and university research and creative incentives for firms to train their workers [9].

Currently, South Africa fails to produce enough qualified teachers in the fields of science, mathematics and technology. The universities produce only 160 science and mathematics graduates a year. South Africa needs to be producing ten times this number for the next decade in order to close the gap in qualified teacher needs in these fields [9].

Among the teachers who are currently practising in South African schools, only 50% of mathematics and 42% of science teachers are qualified in their fields. South Africa has a shortage of 4000 mathematics teachers and 12000 science teachers, and 16000 practising teachers need further training. More than 40% of science and mathematics teachers have less than two years of experience [9].

If South Africa wants to succeed in the world market it has to manufacture materials instead of only supplying raw material; but this cannot be done without science, mathematics and technology [9].

South Africa extended access to the Internet between 1998 and 2000, when the number of users doubled, but this progress is tempered by the lack of trained individuals in the vital fields of science and technology.

Many difficulties occur in South African schools and some quick and efficient solutions must be encouraged for meeting the challenges of the new era where science and technology are in a rapid change. Therefore both teacher training and science and technology teaching at schools also require some important changes and new approaches. According to Kahn, technological development must be based on science, mathematics and technology education

[10]. Of particular relevance to the current research study is his policy that the curriculum should include the scientific and mathematical understanding of technology in everyday life, such as: rehydration, how to attach a three-pin plug to a kettle, jump-starting a car, the nature of air and water pollution, appreciating risk and financial planning, and so on. He emphasized that science and technology education plays a crucial role in the development of a country, and it can be considered as a measure of its development. These arguments support the main principles forming the basis of Outcomes-Based Education (OBE).

Origin of the Problem

The results of the Third International Mathematics and Science Study-Repeat, TIMSS-R, disclosed that, in general, conditions for learning science and mathematics in South Africa were not favourable compared to the 38 other countries which participated in this study [11]. The majority of the South African teachers whose students participated in this study also reported that they did not feel confident about their own preparation as science and mathematics teachers.

From the results of TIMSS-R, Howie concluded that the challenges for education in South Africa are continuing to mount; and that much has to be done in the coming years to improve the quality of South African education - in particular science and mathematics education. She also stated that, if South Africa wants to succeed in a rapidly changing and competitive technological world, there is an urgent need to increase the number of pupils with adequate and well-founded knowledge and skills in science and mathematics to create a critical mass of matriculants who are able to move into higher education, business and industry in the short, medium and long term.

The development of a modern society requires scientifically and technologically literate people. A recent Senior Phase policy document of the South African Department of Education required learners to demonstrate an understanding of the application of scientific and technological processes to solve problems and satisfy needs and wants [6]. It also emphasized the importance of understanding the impact of science and technology on people's social life, on the economy and on the development of society. Hence, it is in this wider context that the present investigation is located.

Statement of the problem

Many studies have been conducted during the last few decades to determine the levels of scientific and technological literacy and the conceptual difficulties of science learners and teachers [13] – [19]. However, in most of these studies the adopted assessment research instruments consisted of paper-and-pencil type tests only, which is not necessarily what active science and technology is all about and what OBE requires from 2003 onwards.

Hence, this current research study explores the feasibility and efficacy of a systematic, practical, task-based approach to diagnostic assessment in everyday technical and scientific situations. Instead of using a paper-and-pencil type of evaluation, a hands-on exploratory programme which comprises a sample of 17 formulated assessment tasks using manufactured items (selected out of an experimental pool of 33 trialled items) has been used to gather detailed response data from different voluntary groups of students of science, technology and engineering in wide range of contexts in South Africa.

Context of the study

OBE, which encourages the attainment of science process skills through teaching the Natural Sciences learning area, is currently being implemented in South African schools [6]. In the new science textbooks that employ an outcomes-based approach, the relevant topics are presented and introduced by means of a variety of activities through which learners are expected to attain these process skills and handle different items of apparatus [20]. Therefore, in an OBE system of education, learners are expected to be able to use, handle and perform tasks and make measurements with different items of simple apparatus and equipment.

The recent 2002 Revised National Curriculum Statement (p.6) has introduced three defined learning outcomes for the Natural Sciences. The first outcome specifies that the learners acquire eleven science process skills: viz *observing and comparing; measuring; recording information; sorting and classifying; interpreting information; predicting; hypothesizing; raising questions about a situation; planning science investigations; conducting investigations; communicating science information* [6].

Isaacs has argued that merely learning about science and technology theoretically does not bring about a complete understanding of their principles, laws and concepts. Learners must also be given opportunities to work in ways scientists and technologists do. Actually doing science not only develops the specific skills but also enhances the learning of scientific and technological principles, laws and concepts [21].

Rillero pointed out that science **process skills** drive the **doing** of science and technology, and science **content** knowledge is the **knowing** of science. He stated that any ability that helps a person to do science is a science process skill - such as *observing, inferring, classifying, questioning, predicting, experimenting, analyzing data* and *communicating*. He argued that gaining such skills is not only important for those who pursue a science-related career, but also because it is difficult to imagine a career in this millennium that does not involve science and technology. Rillero stated that science and technology content knowledge and process skills are important and complementary. He argued that activity-based learning could offer a context for both [22].

Brotherton and Preece investigated several postulated hierarchies of science process skills and they observed only a two level hierarchy (basic and integrated) of process skills, and they found no evidence to support a theoretical multi-level model. They also reported finding an overlap between developmental level and competence in process skills. Two-levels of skills hierarchy were observed to be in parallel with concrete and formal levels in Piaget's scheme [23].

Auntoh and Woolnough investigated and discussed the generalisability of six selected laboratory-based process skills: *preliminary trials, planning, performing, communicating, interpreting* and *feedback*. They observed that two of the six skills (*preliminary trials* and *planning*) were generalisable; one (*interpreting*) was context-dependent; and three (*performing*, *communicating* and *feedback*) were inconclusive [24]. This implies that the attainment of these process skills by learners may be a challenging task for educators. Innovative and creative ways of dealing with this type of instruction may be required.

Harlen also argued that science process skills are important - not only in terms of preparing future scientists and technologists, but also for the whole population who need scientific literacy in order to live and function in a world where science impinges on most aspects of personal, social and global life [25]. Therefore the acquisition of science process skills also needs to be assessed in schools, technikons and universities, as well as an understanding of science concepts as end products. He discussed the assessment of process skills for three purposes: formative, summative, and national and international monitoring. He stated that learning with understanding involves linking new experiences to previous ones. In this way ideas developed in relation to specific phenomena become linked together and they become ‘big ideas’ to have more explanatory power. The development of science process skills in young learners is crucial in this approach: if these skills are not developed well, contrary evidence emerging from new experiences may be ignored and preconceptions will prevail. This will not help understanding of the world.

Harlen, however, pointed out that it is important to assess process skills only when conceptual understanding is not an obstacle to using these skills. If learners are experiencing problems in comprehending the related scientific concepts (content) they may not be expected to use process skills to apply their understanding of these concepts [25].

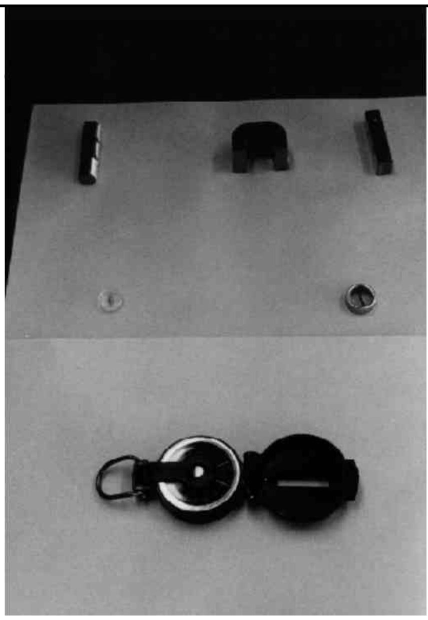
In the South African curriculum, Continuous Assessment (CASS) can be used for five purposes:

- Baseline assessment: to establish what the learners already know.
- Diagnostic assessment: to find out about the nature and the causes of the learning difficulties experiences by learners.
- Formative assessment: to monitor and support the process of learning.
- Summative assessment: to provide an overall picture of the learner’s progress at times when an overall progress report is needed.
- Systematic assessment: to assess the education system at regular intervals, carried out at national level [6].
- In science and technology, continuous assessment is especially applicable and relevant to evaluating learners’ progress in mastering both content (concepts) and process skills.

METHODOLOGY

The Workstation activities

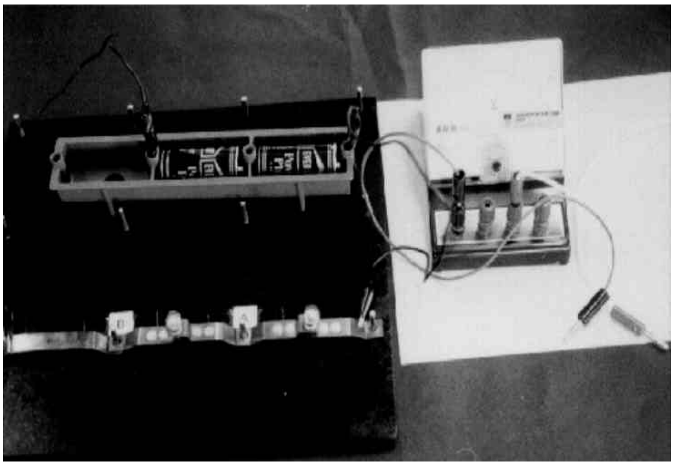
The activities of the compact programme were selected to include actual manufactured items of apparatus with written instructions which explain what was required of the participants. Photographs of two of these items are depicted in Figure 1 below.



A compass and three magnets with different shapes.

Instructions:

Look at the unmarked magnets and the compass. Use the compass to identify the *North Pole* of each magnet.



A circuit that involves two cells in series with two bulbs and an ammeter connected to the circuit at point A.

Look at the circuit given

a Indicate the direction of the conventional current going through the circuit (Away from the + pole of the cells or Towards the + pole of the cells).

b Read the value of the current at the ammeter which is going through point A.

c Guess how much current goes through point B.

Figure 1 Photographs of samples of practical items of the study

Development of the programme

The practical task items of the study underwent eleven pilot trials over a period of one year before they were taken to other institutions for actual data collection. During these trial periods, the sessions were usually limited to 30 to 50 minute periods/lectures at various institutions in Cape Town.

Sample and site

Together with the pilot stages the programme was conducted with 28 sample groups of participants ranging from classes of engineering and science graduates and their lecturers, down to high school science classes across a wide spectrum of socio-economic areas. At the end of this period, which took place over two years, a pool of final data from 340 participants had been collected for statistical analysis of the programme and comparisons of the participants' performances.

Basic statistical properties and parameters of the items

Table 1 records the means, standard deviations and α-coefficients for the individual practical tasks obtained with a total of n=340 participants, and also for the test as a whole. Although the value of α (Cronbach) is 0.58, which is moderate, according to Prof. M. B. Ogunniyi (personal communication, 13th October 2000), "The reliability of **practical** test items is customarily uncertain". When Harlen (p.139) examined science process skills and their assessment, he pointed out that the **validity** of the instrument was more important than its reliability. Thus, an alpha-coefficient of 0.58 for this compact practical skills programme as a whole is not unsatisfactory. Furthermore, removal of three activities, namely items 2, 3B and 5, could improve the coefficient cronbach alpha to 0.65 for the programme as a whole, if desired.

Table 1 Parameters and statistical properties of the final ten core items (consisting of 17 individual tasks) for a combined sample of n=340 test participants, and the theoretical effect of deleting single practical task items on the Cronbach alpha coefficient for the whole compact programme (α=0.58, whole test)

Items/activities	n	Mean	SD	Max.	Cronbach alphas		Item-to-total correlation	Alpha if deleted
1. Displacement volume	340	1.82	1.31	3	-		0.37	0.53
2. Shoe pressure	340	0.55	0.50	1	-		-0.11	0.60
3A. Magnet A	340	0.41	0.49	1	0.48		0.19	0.56
3B. Magnet B	340	0.52	0.50	1			-0.07	0.60
3C. Magnet C	340	0.46	0.50	1			0.11	0.58
4A. Electricity: light globe cost	340	0.95	0.22	1	0.12	0.50	0.19	0.57
4B. Electricity: Light globe brightness	340	0.94	0.24	1			0.18	0.57
5. Electricity: Refrigerator light	340	0.73	0.93	3			-0.01	0.62
6. Electricity: duration	340	0.28	0.45	1	0.61		0.27	0.55
7. Electricity: resistance	340	0.55	0.67	3			0.40	0.52
8A. Electricity: current direction	340	0.68	0.47	1			0.23	0.56
8B. Electricity: Ammeter reading	340	0.37	0.63	2			0.30	0.55
8C. Electricity: Current estimation	340	0.53	0.83	3			0.43	0.51
9A. Light: Concave mirror	340	0.64	0.48	1	0.85	0.67	0.36	0.54
9B. Light: Convex mirror	340	0.61	0.49	1			0.39	0.54
9C. Light: Plane mirror	340	0.79	0.40	1			0.50	0.53
10. Light: Lens image	340	0.24	0.43	1	-		0.06	0.58
Total score	340	11.06	3.91	25	0.58			

Table 1 explains how the Cronbach alpha coefficient for the test as a whole would be improved (marginally) by the removal of individual items. However, since deletion of items 2, 3B and 5 from the compact programme would have only slight effect on the total reliability, all 17 activities were retained for the analysis of the participants' scores in order to maintain content validity. However, hypotheses involving the unreliable activities 2, 3B and 5 taken individually, must be treated very cautiously.

Figure 2 records the distribution of the whole test score totals obtained with the 340 participants, and illustrates the close to ideal normal distribution of scores obtained for the programme as a whole.

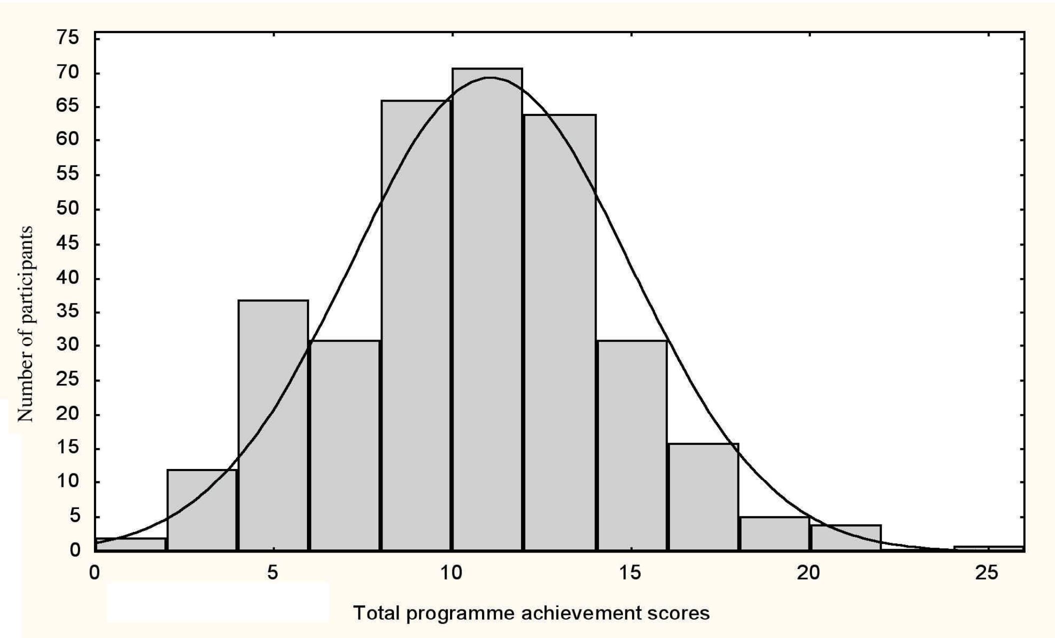


Figure 2 Distribution of the total scores on the compact programme of 17 practical activities by a sample of n=340 participants (Maximum possible score = 25).

Table 2 presents the item analysis for all 17 activities in terms of their acceptable levels of difficulty, and in terms of their ability to discriminate between high and low achievers on the compact programme as a whole.

To calculate the difficulty and the discrimination indices of the items, the upper and lower 27% of achievers on the total test scores were used to perform the calculations of the individual item difficulty and discrimination indices. In this research study 27% of the 340 participants is calculated to be 92 participants, so the achievements of the top 92 participants have been compared with those of the bottom 92 participants, item by item.

In table 2:

NU: Number of participants who were in the top 27% of the sample

NL: Number of participants who were in the bottom 27% of the sample

$$d = \frac{(92+92)-(NU+NL)}{(92+92)} \times \frac{100}{1}$$: Difficulty index

Table 2. Item analysis: indices of difficulty and discrimination

Item/ activity	NU (correct upper)	Correct Upper %	NL (correct lower)	Correct Lower %	(NU+NL)	Difficulty Index (%)	NU – NL	Index of Discrimination $D = \frac{NU - NL}{92}$
1	90	97.8	28	30.4	118	35.9	62	0.67
2	61	66.3	24	26.1	85	53.8	37	0.40
3A	52	56.5	22	23.9	74	59.8	30	0.33
3B	49	53.3	48	52.2	97	47.3	1	0.01
3C	57	62	35	38.0	92	50.0	22	0.24
4A	92	100	81	88.0	173	5.98	11	0.12
4B	92	100	80	87.0	172	6.52	12	0.13
5	47	51.1	11	12.0	58	68.5	36	0.39
6	51	55.4	45	48.9	96	47.8	6	0.07
7	71	77.2	9	9.78	80	56.5	62	0.67
8A	83	90.2	44	47.8	127	31.0	39	0.42
8B	58	63	17	18.5	75	59.2	41	0.45
8C	63	68.5	10	10.9	73	60.3	53	0.58
9A	78	84.8	26	28.3	104	43.5	52	0.57
9B	91	98.9	37	40.2	128	30.4	54	0.59
9C	77	83.7	19	20.7	96	47.8	58	0.63
10	28	30.4	17	18.5	45	75.5	11	0.12

Indices of discrimination are customarily interpreted as follows:

D>0.50 excellent;

0.50>D>0.40 very good;

0.39>D>0.30 good;

0.29>D>0.20 fair;

D<0.20 weak [26].

Table 2 partly justifies the retention of the queried **item 2**: **shoe pressure**. Its index of discrimination (0.40) is very good, and its difficulty level (53.8%) is close to the ideal of 50%.

Table 2 also justifies the retention of the queried **item 5**: **electricity: refrigerator bulb**. Its discrimination index (0.39) is good, and its difficulty level (68.5%) is also acceptable.

However, **activity 3B: magnet B** is of dubious reliability. It also fails completely to discriminate between high and low achievers on the compact programme as a whole. However its level of difficulty (47.3%) is almost ideal.

Lastly, **activity 4: light globes** is perhaps too easy; whilst **activity 6: electricity duration** and **activity 10: lens image** are weak discriminators.

However, the main overall decision emerging from the results presented in Tables 1 and 2 was that all 17 practical task items would be provisionally retained in the compact programme for subsequent statistical analyses, because, although several items are not entirely ideal in all the desirable aspects sought, they do have identifiable strengths.

Also, it was discovered that the total achievement scores of the diverse sample of n=340 participants manifested an ideal near-normal distribution of scores on the programme as a whole. This is pleasing, since bimodal distributions commonly tend to occur with teacher-made tests, unless the items are trialled and carefully refined, so this common mistake has been avoided in the formulation and compilation of this particular compact practical programme [27].

FINDINGS

a) Achievement scores

The statistical analysis of the results of the study showed that English proficiency level of participants was associated with their performances on the programmes as a whole and also on individual items.

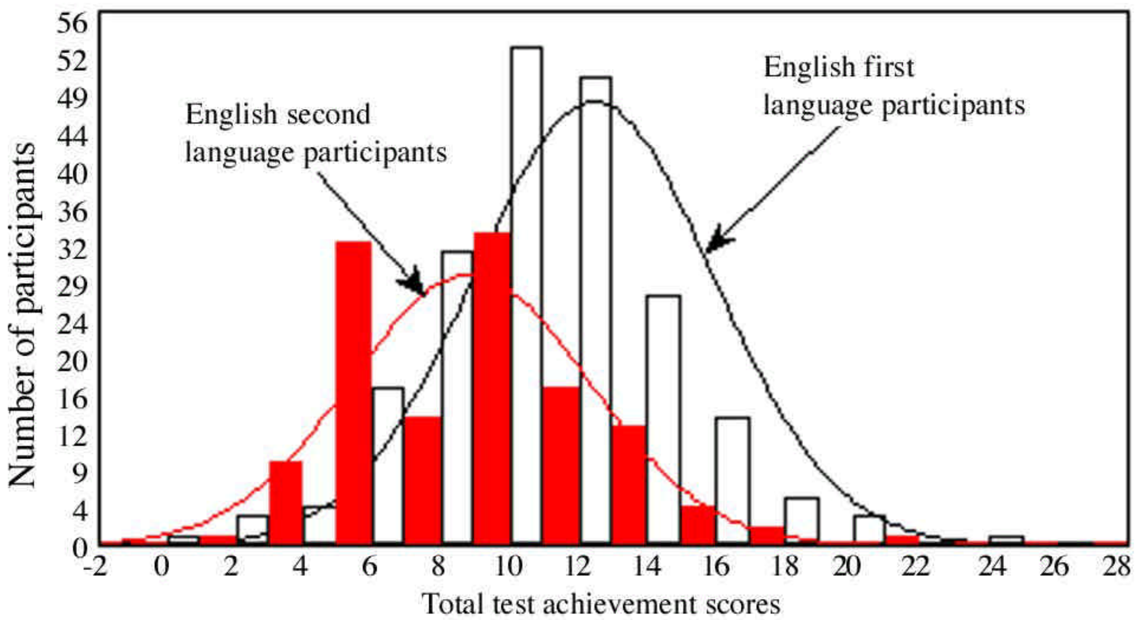


Figure 3 Total achievement scores of participants classified according to their English Language proficiency

In order to be able to make deeper analyses of the language factor, the English second language participants were divided into two categories according to where their schools were situated. The students who attended schools in townships (informal settlements) formed one group and students who attended more privileged schools formed another group. The reason for this was the fact that in the schools located in townships, students tend to converse in their own tongues (not English) with their peers and family members. This contributes to poorer proficiency in English, because for them English is a classroom language only. This may imply that the proficiency in English may have more influence than whether it is their first or second language. It was observed that English second language science and technology students who were attending non-township schools performed significantly better than those at township schools, as recorded in Table 3.

Table 3. The total achievement test scores of participants classified according to their English Language proficiency.

	n1	n2	Mean 1	Mean 2	t	df	p
All English first language vs. All English second language	212	128	12.42	8.81	9.20	338	0.000**
All English first language vs. Non-township English second language	212	19	12.42	10.95	1.78	229	0.76
All English first language vs. Township high school English second language	212	85	12.42	7.55	11.49	295	0.000**
High school English first language vs. Non-township high school English second language	184	19	11.89	10.95	1.22	201	0.22
High school English first language vs. Township high school English second language	184	85	11.89	7.55	10.74	267	0.000**
Non-township high school English second language vs. Township high school English second language	19	85	10.95	7.55	5.03	102	0.000**

** $p < 0.01$

In Table 3, "All English first language" refers to all of the 212 English first language participants, "All English second language" refers to all of the 128 English second language participants, "Township high school English second language" refers to the participants who are at the high schools situated in Townships, "Non-township English second language" refers to English second language participants who are **not** at schools in geographically underprivileged areas such as Townships.

The following figure depicts the distribution of the performance scores achieved by these sub-groups of participants categorised according to their English proficiency levels.

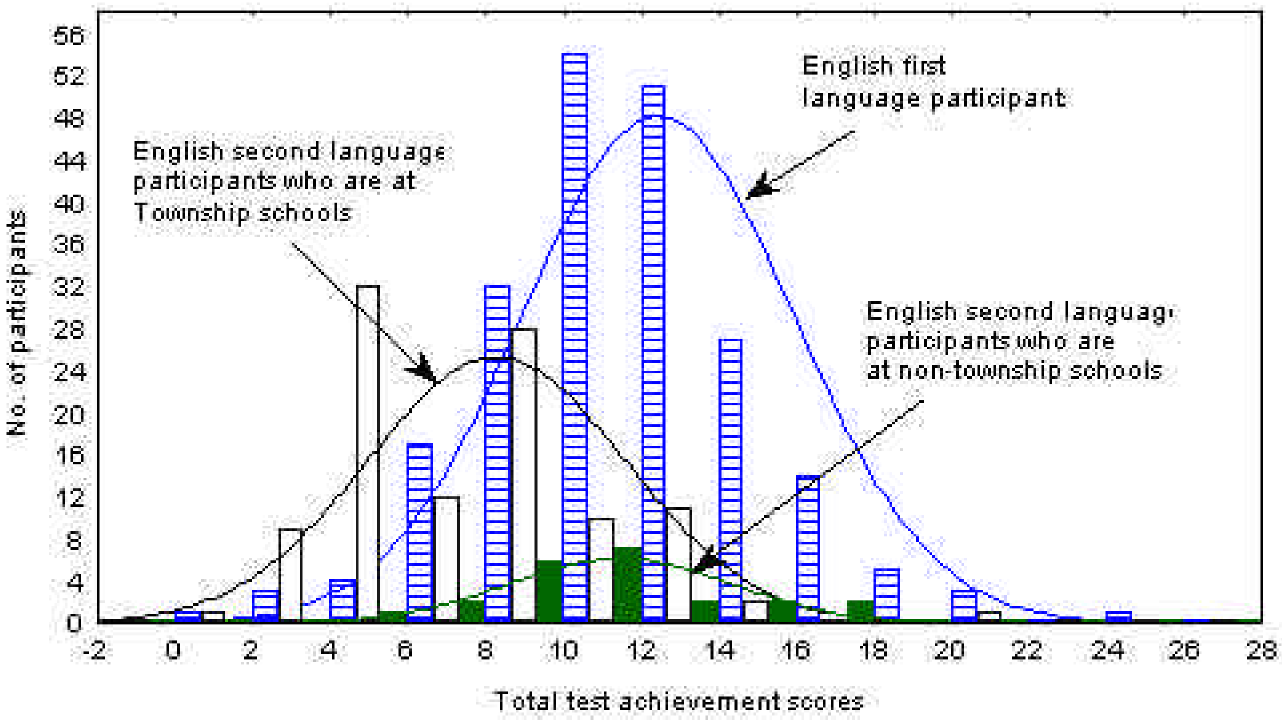


Figure 4 Total achievement scores of participants according to their English proficiency levels and geographical areas

When compared with the secondary level participants the tertiary level participants achieved significantly higher. However there were some tertiary level participants who achieved below 10 (out of 25), indicating that they were failing in such activities of basic practical science and technology.

b) Affective qualitative responses to the programme

In oral interviews, some of which were tape recorded, the participants at both secondary and tertiary levels showed and recorded a high level of interest and enthusiasm towards the practical items as they were trialled and developed during the study. In their concluding evaluatory written comments on the exercise, participants used the words *interesting* (83 times), *good* (76 times), *enjoyable* (51 times), *fun* (43 times), *exciting* (16 times) and *challenging* (7 times). Reproduced in more detail below are 20 representative affective comments from students in science and technology, quoted verbatim:

"I feel that this test was very unique and different. It was unusual but very interesting".

"This is interesting way of learning".

"I find electricity quiet interesting because it is applicable".

"I found magnets and mirrors aspects more interesting".

"I felt that this exercise was a good method for determining prior knowledge".

"This is a very good way of learning".

"I enjoyed this it was fun".

"I agree that basic science is necessary for everyday life".

"I especially enjoyed the mirrors".

" I would like to have another (practical) test because the more we test ourselves the more we learn".

"I pick up information more quickly when I observe and do it".

"It is easier to understand when all five senses are involved".

"I think practicals allow you to learn more efficiently because you come to your own conclusions".

"I remember things better when I work with actual apparatus".

"I would like it to be explained further".

"Science is a very intense subject and should be made interesting by alternative methods".

"Practical work and theory must be mixed".

"This is a very good way of learning, it cannot all be taught like this. It should also be explained by teacher".

"Thank you for a very nice lesson".

It was also observed in some of the comments that the participants who found some items difficult either were not continuing physical science as a subject at school or had wary attitudes towards it. For example, one high school student wrote: "*The word 'science' makes me nervous*". Another student wrote; "*I hate science but I don't mind practical work*".

c) Cognitive qualitative responses to the programme

In addition to the positive affective comments made by the participants, there were instances when approximately 30 individual participants indicated that they found some of the technical items difficult, either partially or as a whole. Nevertheless, another 65 participants explicitly indicated that they did not find the technical items difficult.

The participants also gave their perceptions regarding the value of the programme as a whole for cognitive learning. A total of 88 respondents indicated that their participation in the programme contributed positively to their understanding in the covered areas of science and technology. Some of these comments extracted from recorded oral interviews and form their written evaluations included the following;

"I would like to have another (practical) test because the more we test ourselves the more we learn".

"I pick up information more quickly when I observe and do it".

"It is easier to understand when all five senses are involved".

"I think practicals allow you to learn more efficiently because you come to your own conclusions".

"I remember things better when I work with actual apparatus".

"It is easy to remember".

"I would like it to be explained further".

"Science is a very intense subject and should be made interesting by alternative methods".

"I find electricity quiet interesting because it is applicable".

"Magnifying glasses were very interesting".

"I found magnets and mirrors aspects more interesting".

"I really enjoyed looking at the objects. I would rather prefer this to the teacher explaining them to us".

"I thought it was really cool. I really enjoyed looking at and touching the different objects".

"If you just sit and listen all the time you tend to forget but when you experiment you remember it in the future".

"I prefer it when we examine the actual thing, but it can be confusing sometimes".

d) Second stage analysis

A total of 408 written comments were received from the 340 participants. In a second stage analysis of this data, the important substantive issues and themes reflected in these written comments emerged as:

- The necessity for teachers to make science and technology lessons more interesting continuously;
- The importance of relating school science and technology to the everyday lives of the learners;
- The importance of motivating learners to participate in classroom activities; and

· The necessity for setting alternative targets for learners who do not plan to pursue a career directly related to science and technology.

Other aspects commented on by some of the respondents included the attitudes of individual participants towards science, and their perceptions of the difficulty and nature of the subject. Unexpected perspectives mentioned by individuals were: a negative attitude towards homework and textbooks; the perception that science is necessary but mostly uninteresting; the importance/desirability of involving computer-related issues in science; and the suggestion that this type of programme practice should be used in other school subjects as well.

e) Interviews

During the course of the development, refinement and improvement of the wording and presentation of each workstation, with its apparatus and instructions, extensive face-to-face discussions and interviews were held and recorded with science academics, science teachers, science teachers-in-training and children in science classes ranging from the wealthiest to the most impoverished. These have been reported elsewhere [28-30].

f) The science process skills involved in the current study

An additional analysis of the relevance of these skills to the current programme by the panel of eight experienced school science and technology teachers revealed that *observation skills* and *communicating science information* were involved in almost all of the items. The participants also recorded an awareness of the importance of these skills.

During the course of extensive field-testing, it was also discovered that there also exist certain skills that are not explicitly specified in the Natural Sciences Learning Area of the 2002 Revised National Curriculum Statement, but which were encouraged by the compact programme. These included: (1) skills in expressing scientific notation of units accurately, (2) skills in translating mathematical formulas/expressions into meaningful texts, (3) skills in accurately comprehending written information and instructional procedures, (4) skills in applying conceptual understanding to practical situations, and (5) skills in visualizing and linking school science and technology content to everyday experiences.

Discussion

The panel of eight independent experienced science educators evaluated the final version of the compact programme of this investigation summatively and they agreed it was relevant, efficient, objective, valid, specific and fair. However, in its design and construction it was deemed to be not completely satisfactory in terms of balance, difficulty, reliability and discrimination. The programme included examples from only certain chapters of the school science and technology syllabuses, indicating that it was not fully representative in terms of the range of the topics it covered, due to restrictions in school time available for its trial and administration in classroom.

In terms of difficulty and discrimination, the compact programme included some items which failed to discriminate sharply between high and low achievers, and which did not have statistically acceptable difficulty levels, such as activities 1, 3B, 4 and 9B. However, the inclusion of these items in the final statistical analysis of the results, was justified by other criteria.

The programme encouraged participants to demonstrate their proficiency in, or guided self-discovery of, certain process skills that have been briefly discussed above. However, more graded skill levels could be involved in the further development of a programme of this nature. Some of the activities measured low level skills (e.g. identifying the bulb that would cost less or glow brighter; recognising and manipulating different types of mirrors; etc.), while others involved moderately complex skills and knowledge (e.g. measuring volume, and identifying unmarked poles of magnets) and higher order skills and content knowledge (e.g. calculation of resistance, and obtaining real images with lenses). Visser's "stations" strategy is also a good related example of this nature. It starts with a relatively simple question and builds on it [31].

In the present study, the participants were also given an open-ended question to express their ideas after they had completed all ten workstations. In the future, for the same purpose the participants might be given a list of possible views and asked to rate them, as well as the open-ended question.

Since the written instructions of the field-tested practical tasks were only in English, some of the English second language speakers hesitated initially in comprehending the requirements of some of the technical items, despite earlier successive amendments of these instructions. For such learners, the future language wording of the items could even be simplified further. However, this weakness was considered minimal for the sake of the whole investigation. An unresolved issue is that the participants who experience problems with the language were those schools, universities and technikons where people converse in languages other than English.

In South Africa, Hanrahan identified eight competencies that an engineering graduate should have:

- Identify, assess and solve engineering problems of a non-routine nature, within limits of own knowledge, creatively and innovatively.
- Apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems.
- Design components, systems and processes taking constraints into account, assessing the financial and social costs and benefits, and taking other impacts into consideration.
- Plan and conduct investigations and experiments.
- Analyse and interpret data and derive information from data.
- Communicate effectively in writing and orally with superiors, peers and subordinates.
- Engage in life-long learning, based on lifelong learning as a professional value.
- Recognise the need to act professionally and ethically within own area of competence [32].

This study has aimed to report the outcomes of an investigation into the diagnostic utility of a technical programme of basic workstation activities relevant to the development of competencies 2, 4, 5 and 6 when a large proportion of students are speaking English as a second language, and have little previous experience with practical work in science and technology.

Conclusions

Despite several shortcomings, the overall outcome of the compact programme of practical activities may be considered as generally satisfactory in terms of its intended diagnostic contribution to teaching the Natural Sciences and Technology Learning Areas, as presented in the most recent 2002 curriculum policy documents in the preparation of future engineers and technologists in a developing country. Since Australasia is close geographical proximity to many emerging nations who also speak English as a second language, it is anticipated that this research study may be both timely and relevant to members of Australasian Association of Engineering of Education when working with under-prepared students at the school / tertiary institutions interface.

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