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Psychometric Testing as a Predictor of Student Performance in First Year Physics Practicals

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INTRODUCTION

Incorporating a practical component into the teaching of university level Physics at a distance poses a unique set of problems. Although both the usefulness and the effectiveness of introductory laboratories in traditional, face-to-face educational settings have often been questioned, the prevailing opinion of a majority of physicists and physics teachers remains rooted in the belief that the practical component is an essential part of any tertiary course in Physics (Arons, 1993). Because the Physics Department at the University of South Africa (Unisa) on the one hand supports the idea that practicals are an integral part of science education while on the other hand acknowledges the findings that there is much to be improved in the design and tuition of practicals (in a traditional as well as in a distance learning setting), it has committed itself to the development of a system for the meaningful presentation of the practical component in higher distance education (Reynhardt, 1987).

Current research on the use of practicals (McDermot, 1991; Kirschner, 1992; Arons, 1993; and Nissani *et al.*, 1994) has shown that one of the major problems with the design and development of practicals in science education is the lack of explicit and valid goals. In line with this research, the first year Physics practical at Unisa is being evaluated with the goal of restructuring it to comply with a valid set of aims and objectives which are relevant in the South African context.

As a first step in this evaluation, a comprehensive student profile for the participants in the introductory physics laboratory is presently being complied. The physics students under consideration form a very heterogeneous population with a wide variety of educational backgrounds, cultures and languages.

Academic performance may be regarded as a product of ability and effort. Whereas ability refers to a person's innate and acquired potential, i.e. his/her aptitude, effort refers to how much work he/she is willing to do which involves personal factors such as motivatioin, values, attitudes etc. Another aspect of importance is of course access to, and quality of training and instruction.

The aim of this research is to try to determine the extent to which aptitude alone contributes to academic performance with specific reference to performance in the introductory level physics practical. An attempt is made to establish which specific aspects or underlying factors of aptitude are the most salient predictors of success in the physics practical. Furthermore, it is attempted to establish whether students' familiarity with the language of tuition has an effect on this relationship between aptitude and achievement and what that effect is (both quantitative and qualitative).

BACKGROUND

To place the research for this paper into perspective, it is necessary to give some background about the presentation of first year physics at Unisa. The University of South Africa has been active in the field of distance education for decades, and since it mainly serves the inhabitants of Southern Africa, the university is concerned with the needs, circum-

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stances and aspirations of these people. Unisa is an institution for higher education to which students can gain entry dependent on whether they have obtained a certificate granting university admission from a secondary school. Courses at Unisa are primarily text based distance educational materials which students can study at home. Unisa makes use of occasionaal group tuition at the various regional centra for achieving those objectives which cannot be achieved in an independent distance setting.

In order to accommodate students from as broad an academic background as possible, the first year physics course is presented at two levels. The complete calculus based first year course in physics consists of three theoretical modules and a practical. Students who do not wish to continue with physics beyond the first year level, have the option of taking the theortical modules at an elementary level which does not involve the use of calculus.

The practical component of the course is presented as a separate module, entitled *Practical work*, which represents a compromise between distance education and face-to-face tution. Upon registration students are provided with a study guide which contains study material on basic laboratory practice, some relevant theory on the experiments included in the practical, and a description of each experiment. The distance education component of the module involves the student in independent work on the material in the study guide and the subsequent submission of four assignments by the end of June. The face-to-face component of the module takes the form of a traditional laboratory based practical, which is conducted during two weeks (i.e. ten workdays) in August at the first year laboratory on the Unisa campus in Pretoria. Admission to the laboratory session is based on the evaluatioin of the four assignments submitted, and only students who have performed satisfactorily in these assignments are admitted to the laboratory session. This not only serves to ensure that students are prepared for the laboratory session, but also prevents students who do not have a reasonable chance of passing the practical module from incurring unnecessary expense in terms of both time and money.

The first day of the laboratory session is devoted to an orientation to the laboratory environment by means of a lecture and a demonstration experiment. Students execute one experiment on each of the next eight days of the laboratory session1. Before beginning work on the experiment of the day, a pre-test dealing with the relevant theory for the experiment is administered. These pre-tests are multiple choice tests which are generated by a computer program which randomly selects relevant questions from a data base of questions for each experiment. In this way each student receives a unique pre-test per experiment. After completing the experiment of the day, students are required to hand in a full written research report which is marked according to a predetermined answer protocol. The topics which must be handled along with the maximum score attainable per topic (in parentheses) are as follows:

1. Introduction		
1.1	Aim	
1.2	Theory	(2)
2. Method		(2)
3. Results		(2)
3.1	Tables	
3.2	Graphs	
3.3	Calculations	(12)
4. Discussion and conclusion		(4)
		[20]

The reason for this emphasis on the interpretation and description of experiments will be covered in the Discussion section of this article. On the last day, the two weeks of activities for the practical module are concluded by the writing of a two hour exam. The exam paper consists of questions on the theory covered in the course of the two week practical, as well as questions on the experiments themselves and the experimental procedures used.

The final mark for the module is based upon the student's marks for report writing (40%), pre-test (20%) and the written exam (40%), aggregated over eight experiments.

METHOD

Subjects

Eighty students attended the Physics I practical session at Unisa in 1994. Of these, 75 agreed to complete a short biographic inventory and to do an aptitude test. The average age of the 75 subjects was 23.32 years, with a standard deviation of 6.53, the ages ranging from 17 years to 43 years. The group consisted of 79% males, and 21% females. The home language of 47% of the subjects was English, 36% indicated an African language as home language,

Table I. Subscales of the SAT Used in this Research

Verbal comprehension	This tests whether the testee comprehends verbal material read by him, and can process it in a logical manner to solve a problem. It is broadly a test of verbal intelligence.
Calculations	This test measures the ability mentally to solve simple mathematical calculations quickly and accurately.
Disguised words	Words are formed from a string of letters and associated with a synonym. Fluency of association is measured.
Comparisons	Sets of symbols are compared, to measure visual perception speed. This relates to speed and accuracy of perceptions of differences between and similarities among visual configurations.
Pattern completion	Testers have to deduce a pattern that enables them to complete a series of items. It is largely a test of inductive reasoning.
Figure series	Items have to be interchanged to place a series of items in a logical order. This is a test of general non-verbal reasoning.
Spacial 2D	An odd item in a set of items is to be identified by rotating figures mentally in a two-dimensional plane. It is a measurement of visualization.
Spacial 3D	A fit among drawings of blocks has to be visualized, as well as finding the odd item in a set of three-dimensional drawings. Visualization is measured.
Memory for paragraph	A paragraph has to be memorized. The basic ability to memorize and remember is measured.
Memory for symbols	Pairs of words and symbols has to be memorized. This test measures the basic ability to memorize meaningless material associatively.

13% have Afrikaans as home language, and 4% indicated a foreign language as mother tongue.

Instruments

Success in the physics practical was determined on the basis of the scores obtained by students on the following criteria:

- Pre-test—a test of the students' theoretical knowledge, based on their preparation for a particular experiment, aggregated over eight experiments.
- Experimental report—an aggregate score on the reports submitted after each experiment.
- Exam—a written exam, taken at the completion of the physics module on practical word.

This yielded a final score (in the later analyses referred to as a fourth criterion) which was a composite score comprising the above scores in the ratio 1:2:2 to a total of 100%.

The first three of these criteria are all significantly intercorrelated, with Pearson correlation coefficients ranging from 0.53 to 0.72. The fourth criterion is obviously correlated, being a combination of the other three.

To test the aptitude of the students, the Senior Aptitude Test (SAT) was used. This test defines aptitude as a specific mental ability, as opposed to a general intellectual ability. More specifically aptitude is the potential which a person has and which enables him/her to attain a specific level of ability with a given amount of training and/or practice. This has an effect on the level of skill and proficiency that may be reached, taking into account individual personality characteristics and environmental factors (Fouché and Verwey, 1988, p. 3).

The SAT contains a battery of twelve tests (subscales) each measuring a relatively independent factor, which together gives a fairly complete overview of the subject's overall mental ability, and which may be regarded as relatively free from the effects of deliberate learning or training. The battery is based on the assumption that a testee's ability to accomplish the intellectual tasks required provides a valid indication of a number of aptitudes that are important for successful academic and technical training. The tasks are (Fouché and Verwey, 1988, p. 4):

(a) Reasoning on the basis of verbal, non-verbal and quantitative material;
(b) word recognition on the basis of a synonym and partial information on the letters with which the synonym is spelled;
(c) visual perceptual speed on the basis of fast and accurate perception;
(d) perception and imaginary manipulation of figures and objects in space;
(e) memory on the basis of the memorization of the contents of a paragraph, words and meaningless material;

(f) rapid and accurate calculations by using the four basic operations in mathematics, and
(g) eye-hand co-ordination on the basis of paper and pencil tests.

The ten subscales of the SAT that were included in this study, are listed in Table I. Since our primary interest is the determination of the role which cognitive aspects of the students affect both their use of and the results of the practicals we have chosen not to include the manipulative tests available in the SAT.

Choosing an instrument for the measurement of aptitude was problematic because no aptitude test which has been standardized for all population groups is available at present, nor are different tests which have been intercorrelated available. Making use of different, non-related tests for different subjects within the group would make any comparison of the results meaningless.

The lack of psychometric tests that are free of cultural and linguistic bias is by no means limited to the South African context (Boyle, 1987; Ho and Spinks, 1988). It is an issue which has led to much controversy with regard to the education of language minority groups like the Hispanic communities in the United States of America (Cummins, 1988).

As the students in the group are expected to do the practical module and to pass the same exam in either English or Afrikaans (the media of tuition at Unisa), it was felt that, although the SAT was developed for and standardised for only one ethnic group, it could be used for the whole group of Unisa students, irrespective of ethnic or cultural background. In other words, non-native language speakers—students with a first language other than English or Afrikaans—would encounter the same problems with the verbal tests on the SAT as they would encounter in the practicals. A further motivation for using the SAT was the fact that its value (the subtest for Verbal comprehension especially), was established by du Plessis (1994) as a predictor of success in a study involving the selection of students for admission to an academic development course at the University of Pretoria.

ANALYSIS

Multiple regression analyses were performed to see whether the aptitude test gives a reasonable prediction of the students' results. Four regression models were constructed with each of the four physics test scores as criterion (dependent variable) and with the raw SAT scores as predictor (independent) variables, for all 75 subjects. Separate regression models on the same variables were also constructed for those students who indicated one of the languages of tuition of Unisa (English or Afrikaans) as their first language, and those who indicated another language as their first language. The first group ($N = 45$) will be referred to as the First Language group, and the second ($N = 30$) as the Second Language group. Of the latter group, 90% indicated an indigenous African language as their first language.

Since part of the goal of this research is to identify which of the SAT subscales may be regarded as the best predictors of success in the physics practical, a stepwise multiple regression procedure was followed. In this procedure, only those predictor variables that made a significant overall contribution to the regression model is present in the final model. Although the procedure capitalizes somewhat on chance, it was felt that, in general, it is a reasonable way to determine the most salient predictor variables in an empirical way, in the absence of any *a priori* hypotheses.

The Multiple Regression procedure of the CSS:Statistica software package was used for all computations (StatSoft, 1991). For the stepwise procedure, tolerance was set to 0.01, F for inclusion was set to 1, and F for exclusion was set to 0.

RESULTS

All Students

Results of the stepwise multiple regression analyses for all students for each of the four criterion variables are given in Table II. The list of predictor variables for each criterion is presented in the order in which they were included in the regression model.

From Table II, it can be seen that the best predictor of the *Pre-test* score for all the students is the SAT variable *Verbal Comprehension*. This variable also makes a significant unique contribution to the model when all common covariance is removed, as can be seen from the partial correlation coefficient. *Spatial 3D* also proves to be of importance in this model. This conclusion is somewhat offset by the fact that the partial correlation is negative, which seems to imply that a high three-dimensional test score is detrimental to a high score on the *Pre-test.* This effect is however only visible when all the other variables present in this model have been accounted for; the

Table II. Summary of Stepwise Multiple Regression for all Students ($N = 75$) for each Criterion Variable[a]

Criterion	Variables included	Partial r	R
Pretest	Calculations	0.23	0.48[a]
	Verbal comprehension	0.30[a]	
	Spacial 3D	-0.25[a]	
	Paragraph memory	-0.22	
	Disguised words	0.17	
Report	Comparison	0.40[a]	0.64[a]
	Verbal comprehension	0.36[a]	
	Symbol memory	-0.16	
Exam	Verbal comprehension	0.19	0.41[a]
	Comparison	0.19	
	Paragraph memory	-0.16	
	Symbol memory	-0.16	
	Figure series	0.14	
Final	Verbal comprehension	0.27[a]	0.55[a]
	Comparison	0.25[a]	
	Symbol memory	-0.21	
	Paragraph memory	-0.20[a]	
	Figure series	0.14	
	Disguised words	0.13	

[a]Significant results ($p < 0.05$).

Table III. Summary of Stepwise Multiple Regression for First Language Students ($N = 45$) for each Criterion Variable[a]

Criterion	Variables included	Partial r	R
Pretest	Symbol memory	0.22	0.50[a]
	Calculations	-0.38[a]	
	Disguised words	0.23	
	Figure series	0.18	
Report	Comparison	0.36[a]	0.51[a]
	Symbol memory	-0.31[a]	
	Figure series	0.34[a]	
	Paragraph memory	-0.17[a]	
Exam	Comparison	0.26	0.51
	Figure series	0.38[a]	
	Spacial 3D	0.33[a]	
	Spacial D	0.23	
	Symbol memory	-0.21	
Final score	Comparison	0.25	0.51[a]
	Symbol memory	-0.28[a]	
	Figure series	0.38[a]	
	Spacial 3D	-0.18	

[a]Significant results ($p < 0.05$).

ordinary Pearson correlation between *Pre-test* and *Spatial 3D* is 0.04, which is not significant. This may therefore be a chance effect and replication of the results may be necessary before its value is proven. Three other variables, namely *Calculations, Disguised Words and Memory for Paragraph* also contribute to the overall efficiency of this regression model, although the unique contribution of each of these variables is not statistically significant.

In the case of the criterion variable *Report,* a high multiple correlation coefficient is found (R = 0.64). The three SAT variables in this model explain approximately 41% of the variance for this criterion ($R^2 = 0.41$). The most important of these predictor variables is *Comparison*, while *Verbal Comprehension* is also statistically significant.

As far as the criterion variable *Exam* is concerned, it appears that although a significant overall model was found, none of the SAT predictor variables in the model make a significant unique contribution. It may be that this model is not very reliable.

The most important variables for predicting a subject's *Final score* are *Verbal Comprehension* and *Comparison*. These two variables make the most important contribution to predicting the score for *Report* and *Verbal Comprehension* makes a significant contribution to predicting the *Pre-test* score.

First Language Students

Table III presents the results of the stepwise multiple regression analysis for each of the four criterion variables when computed for the First Language group. The prediction model for *Pre-test* explains 25% of the variance ($R^2 = 0.25$). Judging by the partial correlation coefficients, only one of the four variables included in this model makes a significant unique contribution to the overall model, namely *Memory for Symbols*. The partial correlation is however negative, which implies that a low score for this subscale is desirable for a high mark on the *Pre-test*. The ordinary Pearson correlation between *Memory for Symbols* and *Pre-test* is –0.19, which is not statistically significant. It therefore seems that this negative effect is present only when the combined effect of all other variables in the model is accounted for.

The most important variable for predicting *Report* is *Comparison*, followed by *Figure Series*. *Symbol Memory* is once again present with a negative partial correlation coefficient. The Pearson correlation between *Memory for Symbols* and *Report* is –0.12, which is not statistically significant.

In the case of *Exam,* the most salient predictor is *Figure Series*. *Spatial 3D* also makes a significant unique contribution, but with a negative partial correlation. The Pearson correlation in this case is –0.08, which is not at all statistically significant.

Table IV. Summary of Stepwise Multiple Regression for Second Language Students ($N = 30$) for each Criterion Variable[a]

Criterion	Variables included	Partial r	R
Pretest	Verbal comprehension	0.43[a]	0.65[a]
	Calculations	0.20	
	Pattern completion	0.22	
	Paragraph memory	−0.21	
Report	Verbal comprehension	0.38	0.72[a]
	Calculations	0.30	
	Pattern completion	0.33	
	Symbol memory	−0.29	
	Spacial 3D	0.25	
Exam	Verbal comprehension	0.49[a]	0.70[a]
	Paragraph memory	−0.35	
	Spacial 3D	0.24	
	Pattern completion	0.23	
Final score	Verbal comprehension	0.47[a]	0.70[a]
	Pattern completion	0.29	
	Paragraph memory	−0.29	
	Calculations	0.20	

[a]Significant results ($p < 0.05$).

The SAT prediction model for the *Final* score is $R = 0.51$, which implies that up to 26% of the variance in this criterion is explained. The only one of the four predictors in this model to make a significant unique contribution is *Figure Series.*

Second Language Students

A summary of the stepwise multiple regression models for each criterion variable is presented in Table IV.

The prediction model for the *Pre-test* explains up to 42% of the total variance ($R^2 = 0.42$). From the partial correlations, it appears that only *Verbal Comprehension* makes a statistically significant unique contribution.

The model for the criterion *Report* explains 52% of the overall variance. In spite of this, none of the five predictor variables in this model make a statistically significant unique contribution. *Verbal Comprehension* is the most salient variable in this model, and approaches significance with $p = 0.054$.

Similarly, *Verbal Comprehension* is the most important variable in the model for predicting the *Exam* score, as well as the only variable to make a statistically significant unique contribution. The same is true of the criterion variable *Final score.*

DISCUSSION

The results obtained here make very clear that Unisa has to deal with two different, but also possibly related problems when it comes to the use of practicals in higher science education. The first problem deals with the language in which the practical module is presented. The second problem deals with the objectives which Unisa should attempt to achieve and the ability of its students to achieve them.

Tuition at Unisa is presented in two languages. This poses no problem for approximately a third of the students attending the university. The other two thirds of the students are, in effect learning in a foreign language. This poses a problem for the learning of factual knowledge, but may pose an even greater problem for the acquisition of the academic or cognitive skills that practicals should set out to achieve. The acquisition of skills, be they mental or psychomotor requires first that the learner has the required declarative knowledge (facts, concepts, theories, etc.) necessary for orienting him or herself to the skill to be acquired and for understanding what has to be done. Clearly a second language student will have greater problems in acquiring this declarative knowledge than a first language student. After having acquired the necessary declarative knowledge the student then proceeds to practicing the skills, constantly getting better, faster and more accurate. Since the skills to be gained in a university setting are primarily cognitive in nature, this means that the student has to mentally manipulate the already obtained declarative knowledge to (re)invent new knowledge or new representations of knowledge (operations on knowledge and operations with knowledge: Crombag *et al.*, 1979). If the student has not gained the necessary declarative knowledge and is then asked—in a language which he or she is not completely proficient in—to manipulate this knowledge, then we would be hard pressed to expect positive results. This may very well be the case for the second language students.

It may be the case that the first languages of these students do not contain the concepts necessary for the learning that is required. Research into the qualities of different languages has shown great differences between languages in their ability to convey conceptual knowledge. From a linguistic perspective, languages differ in the way that they classify experience and therefore conceptual boundaries differ (Brookes and Brookes, 1995). Merritt *et al.*, (1992) refers to the fact that some indigenous African languages do not contain the vocabulary to express scientific concepts. This rules out the possibility of translation, and the consequent use of metaphors for elaboration when explaining scientific concepts can result in logical or factual inconsistencies (Cleghorn *et al.*, 1989). Although it has been found that language does interfere with science learning when taught in English to students with African tongues (Case in Thijs and van den Berg, 1994), it is not the only point of view. It can also be argued that scientific English differs distinctly from the English used in everyday communication. The implication of this viewpoint is that first language speakers go through a process similar to that of second language speakers where first learning to use scientific language, and are therefore in some ways similarly disadvantaged (Brookes and Brookes, 1995).

The influence of language on the construction of scientific knowledge is undeniably culture related, and physics concepts are sometimes ill-matched with the preconceptions or beliefs that exist in certain African communities (Moji and Grayson, 1994). The existence of alternative conceptions in physics is, however, not limited to Africa. In a study including a number of different cultures, Thijs and van den Berg (1994) conclude that the educational starting positions of pupils in various cultures are very similar as far as their preconceptions in physics are concerned. Culture therefore seems to have only a limited influence on preconceptions and superstitions do not seem to affect the formation of concepts (Thijs and van den Berg, 1994).

Finally, the fact that intelligence and language proficiency are generally regarded as being very closely related or even equivalent (Boyle, 1987) could also have a bearing on the results. Boyle (1987) tested the hypothesis that intelligence and language proficiency cannot be considered equivalent but are, in factorial terms, linearly dependent. The results of the experiment provided evidence that inductive reasoning especially as tested with symbols rather than words, is clearly distinguishable from language proficiency. An important conclusion that followed for second language speakers, was that tests which aim at reasoning or memory, but whose questions are framed verbally, are more likely to test vocabulary knowledge than reasoning or memory ability.

The second problem is more epistemological in nature. According to Kirschner (1992) practicals are best suited for the acquisition of cognitive skills. Most practicals today are designed for one of three purposes, namely, to demonstrate or concretize the theory, to achieve meaningful learning via learning by doing, and to instill insight in students as to the phenomena being studied. Each of these purposes, rooted in the belief that practicals should be used for the illustration, confirmation, acquisition or discovery of the substantive structure of science, are fraught with problems. Demonstration and concretization of the theory can be learnt through the use of practicals, but this is an inefficient use of precious commodities (time and money) and runs counter to the philosophy of distance education. Video, CAI, and animation are more suited, and are definitely more effective and efficient than 'wet' laboratories. The assumption that learning by doing is equivalent to meaningful learning, brings two different problems. First, it is an improper translation of what Ausubel (1968) himself said and meant in this respect. He set meaningful learning off against rote learning, but was very explicit in stating that meaningful learning can be achieved by both expository teaching and learning by doing. Second, it is almost surely doomed to failure since the level of knowledge that a person has determines both what he/she sees and what he/she learns. Meaningful expository learning is most often better for achieving meaningful learning than are laboratories. Finally, instilling insight in a student as to scientific phenomena is never a one shot deal. Insight (also called tacit learning or Fingerspitzengefühl) can only be gained through practice. Most phenomena are studied in one or two sessions in experiments which are very time consuming and which consequently do not allow for multiple repetition. Seeing something happen is not the same as gaining insight into what has happened.

Practicals, on the other hand, be they simulations, experimental seminars or wet laboratories are good vehicles for teaching and learning the syntactic structure of science and acquiring cognitive skills. More valid motives for implementing practicals in science education are to help students develop specific skills, for teaching or learning the academic approach to working as a scientist and to allow students to experience phenomena whereby they are capable of achieving a certain tacit knowledge of these phenomena.

This means that redesigning the first year physics practical will have to be approached very carefully in order to achieve the objectives that practicals are best suited to achieve. In other words a double pronged attack needs to be assumed.

Having said this, the results can now be analysed and discussed in this light.

1. It is clear from the results that there are different patterns of predictor variables that are of relevance to the First and Second Language groups of students. Since these differences are concealed when the data for all subjects are analysed together, separate analyses seem justified.
2. The one variable that is of overarching importance for predicting the results of the Second Language group is *Verbal Comprehension.* From this it can be inferred that the biggest problem of students from this group that do badly in the practical, is having to deal with scientific material in a language that is not their own first language. In other words it appears to be the case that students in the Second Language group may experience difficulty in acquiring the declarative knowledge necessary for the mental operations required for acquiring skills. This may also point to inadequate education. It may be worthwhile to consider some kind of introductory course in scientific English for students who have difficulties.
3. In the case of the First Language group, it would seem that the non-verbal aspects of cognitive ability become more important than verbal skills. The only predictor that relates to verbal skills that makes an appearance is *Disguised Words*, in the case of the criterion variable *Pre-test*, and in this case the unique contribution of this variable is not significant. *Figure Series*, which is a general test of non-verbal reasoning and requires the type of manipulation of abstract concepts (analysis) endemic to the above mentioned operations on knowledge and operations with knowledge, is however very important, appearing in all models, in three of the four cases making a significant unique contribution, and in the fourth one nearing significance.
4. To summarise the above two points, it seems that for *Second Language* students verbal ability is of paramount importance for achievement in a physics practical. To those students receiving tuition in their mother tongue, verbal ability becomes less relevant, and it is mainly non-verbal, more analytical abilities that are of importance.
5. In the case of the First Language group, *Memory for Symbols* is consistently present as a negative factor, and in two cases (the criteria Pre-test and Report) the partial correlations are significant. Inspection of the Pearson correlations reveals a slight non-significant negative correlation, which only becomes significant when the composite effect (or common variance) of the other variables in the same model is removed. If it is indeed the case that a good memory for symbols is detrimental to success in the physics practical, the reason for this is unclear. A possible explanation for this is that up until now the factors which played a role in the measures used in this research (tests and reports) were analysis and synthesis abilities as measured in the subscales. Memory for symbols is, on the other hand, a measure for rote learning. It could be the case that meaningful learning is only impeded by the desire to learn things in a rote manner. Thus, the better learners are more likely not to use this rote learning and also it may even be so that those students who employ rote learning (read: are good at it) are at a disadvantage when they are required to perform higher level tasks.
6. In general, there does not seem to be many differences in the aptitude factors involved in each of the four criteria (which is not too unexpected, given the relatively high correlations between them). The salience of *Comparison* in the case of writing a *Report* among First Language students (also visible when all subjects are analysed as one group) may be of importance. Since this task involves comparing sets of symbols, it may indicate that being observant—and perhaps even somewhat pedantic—is of special importance in writing a good experimental report for a physics practical. It should be noted that a good report or reporter is able to compare (analyze) the results obtained during experimentation to a theory or hypothesis that is being studied. If this is the case, then it is not at all strange that students who score high on a comparison subscale will do well when reporting. As a

matter of fact, it should even be expected. Since one of the aims of the practical is to teach students to compare and analyze the results obtained during experimentation to the relevant theory, it can be expected that students who score high on the *Comparison* subscale will do well in report writing.

The interpretation and description of experiments has been found to be an important part of the scientific process. In a comparison of the rankings and objectives for practical work in the Natural Sciences in six seminal studies on this topic Kirschner (1992) found that encouraging accurate observation and careful recording was ranked as most important in four of the studies (Kerr, 1964; Woolnough, 1976; Gould, 1978; Beatty and Woolnough, 1982). In his own research on objectives in higher science education (in both distance and traditional universities as well as higher vocational education) Kirschner found that objectives pertaining to the interpretation of results, the description of the central aspects of an experiment, the presentation of essentials of an experiment in written form, and the communication of experimental findings in written form were among the most important objectives.

CONCLUSIONS

The fact that studying in a second language could prove to be a handicap is generally acknowledged. The results of this research illustrates that the problem may be larger than anticipated. As the results were obtained in the South African context, it is necessary to take into account the fact that the students most of whom make up the Second Language group are representative of the educational anomaly which existed in the country up to now. The implication is that the subjects in the Second Language group, most of whom have poor educational backgrounds, have not had the educational opportunity (in terms of both physical facilities and well qualified teachers) to learn to function at a high conceptual level. On top of this, the fact that these students' secondary schooling was also conducted in a language (English) other than their own first language makes it very plausible that they could have fallen into a pattern of memorising verbal content as opposed to forming cognitive concepts of physical phenomena.

The most important shortcoming in this study was the lack of an aptitude test which was free of culture and language bias. Even so, the very real problem experienced by second language learners that has been uncovered in the process, cannot be disregarded. An immediate and clearcut solution to the problem is not easily apparent, especially since the problem may have its origins in the primary and secondary education of the subjects.

If the problem is to be addressed at its origin, it certainly looks as if the results of this research has definite implications for the language policy with regard to education in South Africa. Although mother-tongue education is the first possibility that leaps to mind, it has become stigmatized as one of the strategies to restrict the social and economical mobility of black South Africans during the apartheid era (Cluver, 1992). Cummins (1988) confirms the problematic nature of finding a language policy for language minority groups with the example of the apparent failure of the so-called English immersion program in the United States. The problem is evidently not restricted to South Africa, as one realizes when Cummins (1988, p. 271) refers to the ways in which children have been disabled by the institutionalized racism that has been part of the fabric of North American schools.

Similarly, Cleghorn (1989) points out that educational opportunities in Kenya can only be truly equitable if the policy regarding language of instruction is brought in line with the actual language needs and practices in urban and rural areas. This statement can be applied with equal conviction to the South African situation. Rutherford and Nkopodi (1990) recommend that teachers employ a mixed language strategy with the amount of vernacular decreasing with the increase in school standard. Such a policy should facilitate the making of concrete-abstract connections across cultural and linguistic boundaries (Cleghorn, 1989).

Amid the politicized nature of the issue of finding a solution regarding the language of tuition for language minorities, Merritt (1992:112–113) makes two very practical, level-headed suggestions, which can certainly be of value in the South African context:

1. Research and workshops are needed to build bridges between indigenous language expressions and the scientific phenomena being taught in the curriculum, perhaps even re-examining the choice of scientific phenomena for instruction in the light of this consideration.

2. With complex sets of new concepts that are not a part of the indigenous cultural expression, teachers can be encouraged to develop the practice of definition, example, and explanation rather than always relying on translation.

The results of this type of action will, however, need some time to come into effect, and some interim measures will have to be taken to show more immediate results. First, it is recommended that all first year students who plan to study physics in a second language should follow an English language course aimed at improving the use and comprehension of scientific terminology. At Unisa a course entitled *Comprehension Skills for Scientists* already exists, but it is not compulsory for all second language physics students. Also, since the recommendation is not to simply translate, but to redefine the content in other terms, the ultimate goal of our project, namely the explicitation of a set of relevant learning objectives will be of the utmost importance.

There is also the very real fact that due to the poorly equipped schools and inadequately qualified teachers that most of the students have had to contend with in their prior education, they arrive at the laboratory session with little or no laboratory experience, and thus with poorly developed experimental skills. In order to address this problem, a home experiment kit is being considered as part of the restructuring of the laboratory course. Research has shown that certain attributes such as spatial perception (Potter and van der Merwe, 1993) which is necessary for the assembling of apparatus and intellectual skills (Reif and St. John, 1979) necessary for the interpretation of results and the relation of experimental outcomes to particular theories are trainable. With this in mind, the kit will be designed to serve the function of preparing students for the practical, with regard to both academic and experimental skills.

The kit will consist of apparatus for home experimentation. The apparatus will be designed in such a way that students living in rural areas who do not have facilities such as electricity and running water, can also use the kit to its full capacity. Manufacturing costs will be kept to a minimum, and objects from the home and environment will be employed wherever possible. Care has been taken not to include experiments which may be potentially dangerous when carried out in a home setting.

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