Addressing the school-university physics practical skills gap

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Introduction

The typical university physics course has a complex structure due to the nature of the discipline. The practical component in particular offers unique challenges. This is even more pertinent in an Open and Distance Learning (ODL) environment like at the University of South Africa (UNISA). Effective ODL education should be flexible enough to accommodate a discipline like Physics with a practical component. The main challenges with practical work in ODL are that students are geographically scattered and that they come from very different educational backgrounds. The target group are adult learners, most of them studying in a second language. But in spite of these constraints, there is an equivalence motive as justification for compulsory practical work as a means to put degrees awarded by ODL institutions on the same level of achievement as those awarded by residential universities.

During the last twenty years the profile of students entering ODL for the first time, has changed noticeably. One of the significant features is the change in average age. It dropped from 31 to 23 years, resulting in the cohort entering ODL directly from secondary school becoming much larger over time. It also means that the skills sets that students come with need to be carefully considered. In the past, thirty year olds would have been in the job market for a number of years, developing job related skills that could be relied on when studying via ODL. School leavers on the other hand, would currently have to rely on what they experienced especially during the last three years of secondary school.

Context

The National Curriculum Statement (NCS) Physical Sciences Grades 10-12 (DOE 2006) indicates Learning Outcome 1 (LO1) as "Practical scientific inquiry and problem solving skills". This outcome is supposed to be assessed at a 35-45% weighting in the Grade 12 end of year examination. Working towards this outcome, Grades 10-12 or Further Education and Training (FET) teachers have to include the following as part of the programme of assessment (DOE 2008):

1. Practical investigations and experiments (one in Physics and one in Chemistry)
2. A research project (this task could involve the collection of data or information to solve a problem or it could be a case study provided by the teacher).

These two aspects imply that a school leaver might only have three opportunities to develop practical skills in Physics during the three FET years. The immediate question would be to what extend a learner could attain practical skills and in particular the science process skills, in a situation as described here?

It is anticipated that school leavers entering the ODL environment should have some basic practical skills. These skills are not only needed in order to cope with the demands of tertiary education in physics, but also with the demands of learning the subject in an ODL setting. ODL teaching experience of the last 10-20 years indicated that the school-university practical skills gap has remained. The question here is what could be done to bridge the gap for these learners?

Framework

The practical skills gap indicated above has been addressed in ODL by using the Learning Cycle (Karplus 1977, Abraham 1998) as an instructional framework and strategy. The three phases of the Learning Cycle are exploration, concept introduction and concept application as illustrated in figure 1. Although usually employed to introduce new concepts and/or address misconceptions, the Learning Cycle has been used successfully for the achievement of the science process skills (Rubin and Norman 1992).

During the first exploratory phase, students explore the concept by performing experiments guided by a general objective and some basic information about the concepts involved. The second phase serves to provide students with a model or concept that explains the observations of the exploration. During the third phase students are given the opportunity to apply the concepts that were introduced. They apply them to new situations, thus leading to a better understanding of the applicable theories or models.

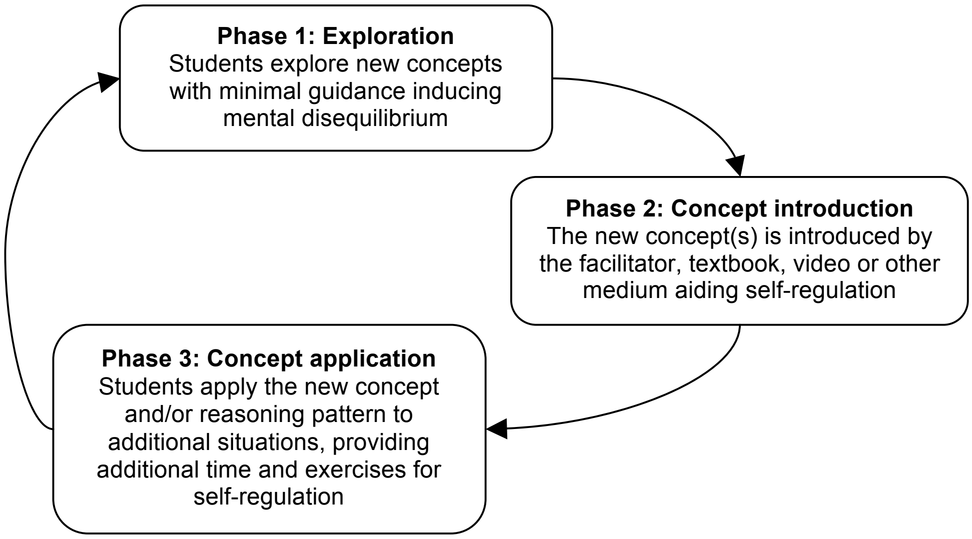


Figure 1: The learning cycle

Links to international trends

Incorporating practical work into Distance Education courses is a worldwide challenge that calls for careful planning and creative curriculum development. While most science educators would agree that studying science without any exposure to practical work would result in a rather idiosyncratic qualification (Bennett *et al*. 1995), there has been growing realisation that the laboratory is not the only place in which all the objectives with practical work can be achieved. Consensus is spreading that the benefit students derive from practical work cannot necessarily be measured by the number of hours spent in a laboratory. Incorporating for example computer mediated systems or experiment kits as components of practical work have been internationally accepted. Examples are the kits used at the Open Universities of the UK and the Netherlands and alternatives to traditional laboratories like Workshop Physics (Laws and Cooney 1997), RealTime Physics (Sokoloff *et al*.1999) and more recently the Physics Education Technology project (PhET) founded by Nobel laureate Carl Wieman (Wieman *et al*. 2007).

Student profile and experience

First level practical work at UNISA is offered as a standalone module PHY103. Although the average age of students entering this module has decreased to 23 years, the age distribution is still 18 to 60+ years. The female component increased over time, but Physics remains a male-dominated discipline with only 25% female students. All national as well as some international languages are represented with 65% of students studying in a second language. PHY103 students are mostly urban and have access to most technologies like computers, phones and television. They come from varied educational backgrounds, but the greatest concern is their secondary school performance in Mathematics and Physical Science. Typically the results would be similar to those shown in figure 2. The 30-35% of the group that performed at the E (40-49%) level and below should be noted.

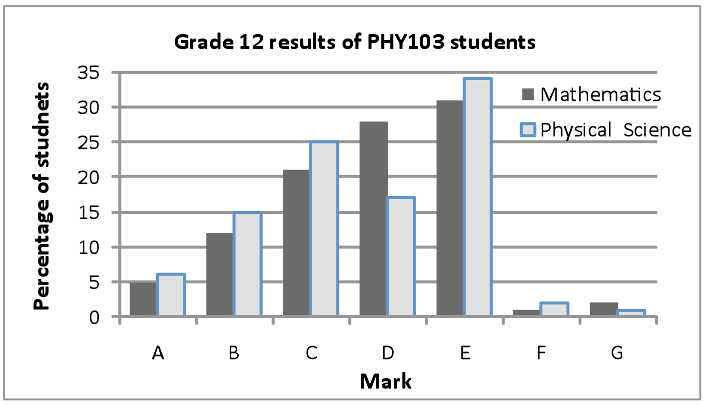


Figure 2: Secondary school performance in Mathematics and Physical Science

Grade 12 mathematics is the only prerequisite for registration in the natural sciences at UNISA and therefore also for the PHY103 module. Concern about students' proficiency in mathematics was proved valid with 41% being categorised as having a proficiency of below average to very poor (Cilliers 1999).

When asked 75% of students entering PHY103 indicated that their schools were equipped with laboratories for physical science, but only 32% saw demonstration experiments more than five times per year. Half of them pointed to the fact that there was no room for discussion before, during or after the demonstrations. Twenty percent said that they had never seen demonstrations and only 16% performed experiments themselves. Apart from rulers and metre sticks, instruments for electrical measurements like ammeters and voltmeters seemed to be used most frequently. Multi-meters and oscilloscopes followed next.

In spite of the fact that ODL students harboured certain negative feelings toward physics as a subject and that 44% perceived it to be difficult, they were almost unanimously positively orientated towards practical work. The positive attitude was seated in students' overriding perception of practical work as an opportunity to get 'hands on' experience of the phenomena, laws and principles they encountered in the theory. Considering that the existing study material at the time was exclusively text based, students' need expressed for concrete exploration of the theory was not surprising.

Objectives of practical work

There is little consensus amongst physicists about the objectives of practical work. In an extensive study about general and specific objectives of practical work in higher education, Kirschner (1991) identified 102 specific objectives from the literature. These objectives were diverse in scope and content and eventually the following groups of objectives were suggested:

1. Developing technical and cognitive skills associated with experimental work
2. Introducing students to the process of scientific investigation and providing the opportunity to gain some experience practicing it
3. Supporting the theory by providing concrete learning experiences
4. Developing affective skills
5. Motivating students by stimulating interest and enjoyment.

The importance of including the science process skills (table 1) in support of objectives 1 and 2 in the curriculum has been motivated on the grounds that these skills can be generalised and reflects the true nature of the activities of scientists (Padilla 1980, Toh & Woolnough 1994). Ways of probing the integrated science process skills proficiency of students (Basson & Cilliers 1997) and the identification of general and specific objectives for specific contexts have been reported elsewhere (Cilliers *et al*. 1999, 2000).

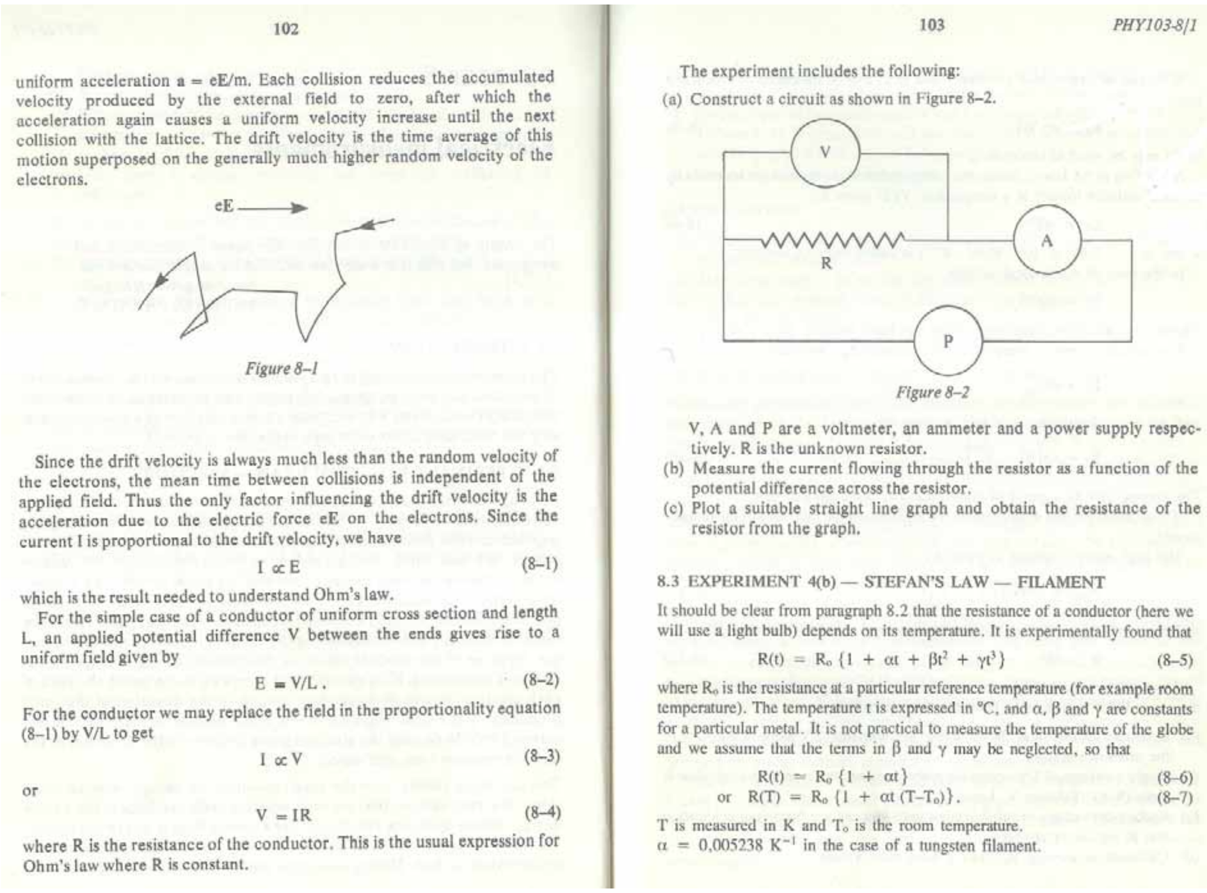
Table 1. Science process skills

Basic	**Advanced**
Observing	Formulate hypothesis
Inferring	Identify and control variables
Measuring	Collect data
Classifying	Process data
Predicting	Interpret data
Communicating	Design experiments

Innovation

The format of practical work at UNISA followed for years a traditional approach of students entering a physics laboratory with little or no preparation and merely following a cookbook style when performing a limited number of experiments. The extent of this is illustrated by the excerpt from the previous study guide of module PHY103 (figure 3). It was realised that this model was outdated, that it did not meet the requirements of effective, contemporary teaching and learning and would never address the skills gap indicated above. A scientifically based model for practical work in a local ODL setting had to be established.

First of all a detailed student profile was determined. Secondly a well defined set of objectives was selected from the research done on this aspect (Cilliers et al. 1999, 2000). Then a model for ODL practical work was developed based on the analysis of these results. Students' expressed need for concrete exploration of the theory was incorporated into the design.



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uniform acceleration a = eE/m. Each collision reduces the accumulated velocity produced by the external field to zero, after which the acceleration again causes a uniform velocity increase until the next collision with the lattice. The drift velocity is the time average of this motion superposed on the generally much higher random velocity of the electrons.

eE ⟶

Figure 8–1

Since the drift velocity is always much less than the random velocity of the electrons, the mean time between collisions is independent of the applied field. Thus the only factor influencing the drift velocity is the acceleration due to the electric force eE on the electrons. Since the current I is proportional to the drift velocity, we have

$$I \propto E \qquad (8\text{–}1)$$

which is the result needed to understand Ohm's law.

For the simple case of a conductor of uniform cross section and length L, an applied potential difference V between the ends gives rise to a uniform field given by

$$E = V/L\,. \qquad (8\text{–}2)$$

For the conductor we may replace the field in the proportionality equation (8–1) by V/L to get

$$I \propto V \qquad (8\text{–}3)$$

or

$$V = IR \qquad (8\text{–}4)$$

where R is the resistance of the conductor. This is the usual expression for Ohm's law where R is constant.

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The experiment includes the following:

(a) Construct a circuit as shown in Figure 8–2.

V A R P

Figure 8–2

V, A and P are a voltmeter, an ammeter and a power supply respectively. R is the unknown resistor.

(b) Measure the current flowing through the resistor as a function of the potential difference across the resistor.

(c) Plot a suitable straight line graph and obtain the resistance of the resistor from the graph.

8.3 EXPERIMENT 4(b) — STEFAN'S LAW — FILAMENT

It should be clear from paragraph 8.2 that the resistance of a conductor (here we will use a light bulb) depends on its temperature. It is experimentally found that

$$R(t) = R_o\{1 + \alpha t + \beta t^2 + \gamma t^3\} \qquad (8\text{–}5)$$

where R_o is the resistance at a particular reference temperature (for example room temperature). The temperature t is expressed in °C, and α, β and γ are constants for a particular metal. It is not practical to measure the temperature of the globe and we assume that the terms in β and γ may be neglected, so that

$$R(t) = R_o\{1 + \alpha t\} \qquad (8\text{–}6)$$

$$\text{or} \quad R(T) = R_o\{1 + \alpha(T - T_o)\}\,. \qquad (8\text{–}7)$$

T is measured in K and T_o is the room temperature.
$\alpha = 0{,}005238\ K^{-1}$ in the case of a tungsten filament.

Figure 3: Excerpt from previous study guide

The design included a

1. Home-based component comprising of a low cost home experiment kit consisting of basic equipment and 'every day' objects, accompanied by appropriate worksheets
2. Restructured laboratory component that built on the instructional approach of the home-based component and that included completely revamped study guides as well as new innovations like computer simulations and updating equipment with regard to technology.

The home experiment kit was developed in two phases. The first phase consisted of a pilot study based on six experiments using very simple equipment comprising a single iteration of the proposed learning cycle. The choice of experiments here was based on two considerations. The topics of uniform circular motion and the simple pendulum involve concepts that contain intricacies which students do not pick up by just studying it from a textbook or study guide. Secondly these phenomena can be investigated using simple 'apparatus' consisting of an object and a piece of thin string. In the second phase the kit was expanded to include experiments covering a range of topics addressing the basic science process skills. This phase also included more experiments that supported the experimental work that would follow during the laboratory session.

The kit was designed to be used in specific order with progressively less scaffolding being provided as students gain experience and proficiency in the specific skills being addressed. By performing simple experiments at home, the gap that existed for students with little or no prior experimental experience was narrowed. It enabled them to arrive at the annual residential type laboratory session not only knowing what to expect, but having already encountered and practised the practical and cognitive skills representing the objectives of practical work.

A workbook with worksheets was written to accompany the kit. Students are made aware of the learning objectives to be achieved at the outset of each experiment. To provide the necessary background on the underlying theory of each experiment, students are referred to specific sections of the prescribed textbook and laboratory manual. With regard to data processing and graphing skills, they are directed to specific sections in a study guide on data processing and experimental procedure. An example of the first page of a typical worksheet is shown in figure 4.

Home experiment B3 – Time

After you have completed this experiment you should be able to

1. **estimate** the time taken by a simple event
2. use a stop watch to **measure** a time interval
3. **report** the findings of the experiment using good scientific language
4. **calculate** the average and the standard deviation of a number of repeated measurements
5. **evaluate** the accuracy with which a timing device can measure time
6. **include** the correct number of significant figures in an experimentally obtained result.

Introduction

Aim

The aim of this experiment is to determine the time it takes to perform a simple action.

Background theory

The fact that all actions take place within a certain interval of time is so much part of our daily lives that we take it for granted, and in the physics laboratory, time is one of the things you will often measure. To understand exactly how one goes about this, we need to formalise the terminology that you are going to need.

In physics we often say that an action starts at time t_1 and ends at time t_2. The time taken for the action, is then

$$\Delta t = t_2 - t_1$$

where the symbol Δt reads "delta t" meaning "difference or change in time" – in other words the time interval during which the action takes place. If one wants to record the time interval during which a certain event occurs – say one wants to know how long it takes to walk to the nearest shop to buy a loaf of bread – one needs to take a reading of time t_1 from a watch at the instant one starts walking, and at the instant one arrives at the shop one has to take the second reading to record time t_2. If I start walking at t_1 = 10:00 and arrive at the shop at t_2 = 10:15, the time I took to walk to the shop was 15 minutes, or differently put, the time interval during which I walked to the shop, was 15 minutes. When we measure time intervals by using a stop watch, the instant at which we press the "start" button is always $t_1 = 0$, so that the second reading t_2 that we take from the stop watch is equal to the time interval we are measuring, i.e.

$$\begin{aligned}\Delta t &= t_2 - 0\\ &= t_2 .\end{aligned}$$

Another way of saying this is that one uses a stopwatch to measure time intervals – think of the way a stopwatch is used at an athletics meeting to time each race. One can also regulate a time interval during which an action takes place. If, for example, one wants to boil an egg for exactly five minutes, one sets the timer to go off after five minutes have passed, so that one can remove the egg from the boiling water at the proper time.

Before you perform this experiment you should read the following from Manual 1 for PHY103-8:

- Study unit 2 *Significant figures*
- Study unit 18 *Writing a scientific report*

Figure 4: Example of a worksheet accompanying the home experiment kit

Structure of practical module

The inclusion of the home experiment kit meant that the complete structure of the practical module had to be improved and changed. The module was re-structured utilising various media within an adapted learning cycle design. Figure 5 illustrates this. It also emphasises the role of assessment within the design.

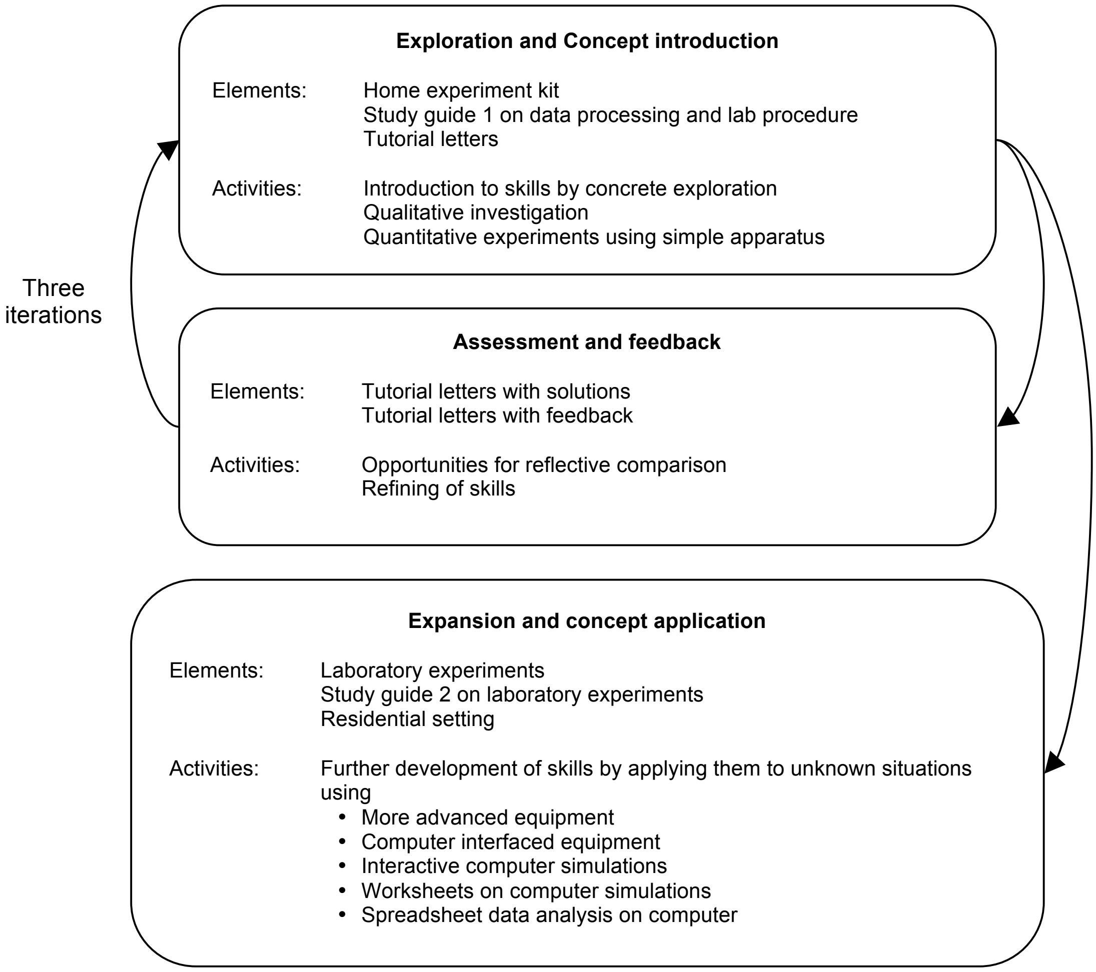

Figure 5: Representation of the learning cycle applied in the design of PHY103

Assessment strategy and results

The content of the module involved experimental as well as cognitive skills therefore the assessment strategy was developed to be integrated as well as multidimensional. It included elements of formative, diagnostic, self and summative assessments. Examples of each are:

1. Formative – assignments on data analysis, worksheet style questions on computer simulations
2. Diagnostic – short tests on concept understanding before experiments are done, reports on experiments
3. Self – practice exercises and experiments with direct feedback
4. Summative – final examination

The effectiveness of the kit was probed by means of students' observations and comments, pre- and post tests and a comparison of their performance in pen-and-paper assignments with assignments using the kit. Figure 6 shows such a comparison of the results of an assignment done with the kit one month after a pen-and-paper assignment. Students not only performed better in assignments, but were unanimous in expressing positive experiences using the kit. The comments were received from younger as well as older students. One of the younger ones wrote:

> *"Thank you tremendously for giving me this opportunity. I honestly gained a lot of experience and am looking forward to my practical examination and the rest of my physics studies. The experiment kit is benefitting all PHY103*

students. I would like to do this thing over again, so let me have a deposit price so that I can do the experiments once more – please. Once again thanks for your time and support!"

An older student was of the opinion that

"To introduce a kit like this to first years is a brilliant idea. I have not studied physics since matric in 1983, so you can imagine how rusted I am. I found these experiments both frustrating and exhilarating. It made the theory practical and I understand it better. I am less scared of the practical session in August. This is one of the best modules I am taking. You have gone to a lot of trouble to make it interesting and stimulating."

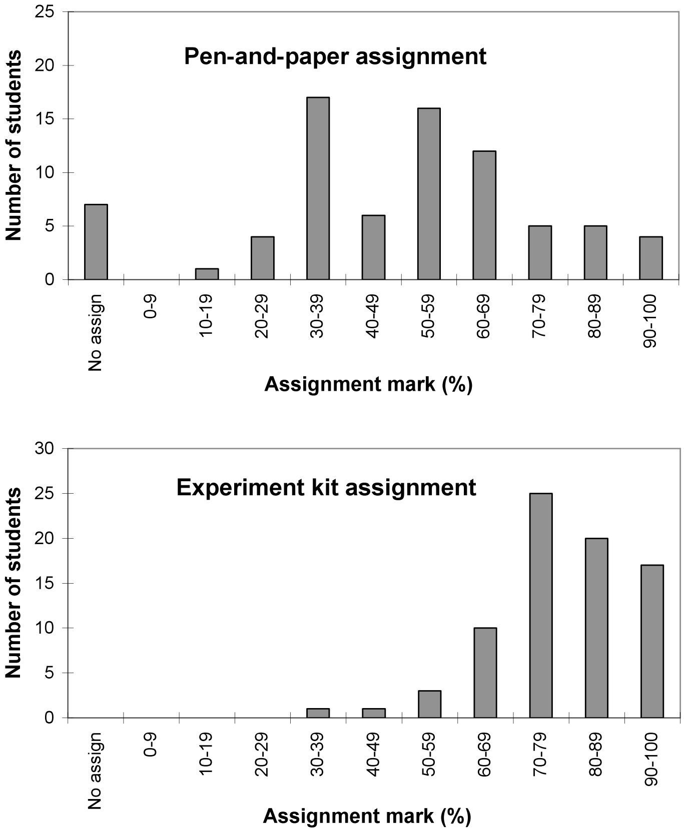

Figure 6: Comparison of the results of a pen-and-paper assignment with a kit assignment

As indicated by the data in figure 2, ODL students do not represent the best talented people entering higher education in this country. A third enters physics studies with grade 12 mathematics and physical science marks of less than 50%. Utilising the teaching and learning strategies with practical work as outlined above, the Department of Physics at UNISA managed to shift at least half of these students on average to a mark higher than 50%. An example of the final marks of a group of PHY103 students is shown in figure 7 for comparison.

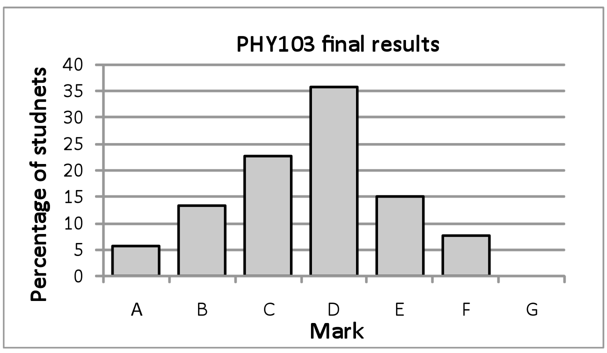

Figure 7: Example of the final results of module PHY103

Conclusions

The intention with the NCS (DOE 2008) is to develop not only the basic science process skills like planning, observing, collecting data and communicating results, but also some advanced skills like generalising and hypothesising. We found students lacking in all aspects of the experimental endeavour when probing these skills at the entry level of university physics. It is clear that it is highly unlikely that these goals will ever be achieved considering the limited or lack of exposure to practical work during the FET phase.

The design and development process of a home experiment kit rendered results of value not only to the practical work module, but for the theoretical work as well. On the one hand there was general consensus about the importance of the development of experimental skills as objectives of practical work. On the other hand ODL students' perception of practical work as an important means to gain hands-on experience of the phenomena they encountered in the theoretical modules became more pronounced as the research progressed. The solution was to design the kit with the dual purpose of fostering the practical and cognitive skills identified as specific objectives of practical work and for concrete exploration of the theory. The kit is therefore providing an opportunity of achieving a broader set of objectives with practical work.

The design of the kit also allows students the opportunity to study independently at any place, any point in time. The approach provides repeated opportunity for practicing experimental and cognitive skills in a process of progressive refinement using simple apparatus and procedures. This finally culminates in a laboratory session where experimentation is conducted at a higher level while using more sophisticated equipment than was possible before.

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