**COUNCIL ON HIGHER EDUCATION**

**AND**

**SOUTH AFRICAN INSTITUTE OF PHYSICS**

# REVIEW OF UNDERGRADUATE PHYSICS EDUCATION IN PUBLIC HIGHER EDUCATION INSTITUTIONS

June 2013

# Acknowledgements

This review has been made possible through the expertise and contributions of many individuals. Particular thanks are due to:

- The late Professor Edmund Zingu, who was instrumental in maintaining liaison and cooperation across the SAIP, the Physics community, and the CHE. Apart from constructing the research instruments, he managed the http://physicsreview.ezi.co.za website which served as the hub of the review;

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- Heads of Physics departments, who advised on review instruments and procedures;

- Academics from Physics departments who participated in Regional Meetings;

- Academics and Students who responded to the online questionnaires that yielded the core data on which this review is based.

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# Acronyms and abbreviations

| | |
|---|---|
| CHE | Council on Higher Education |
| DHET | Department of Higher Education and Training |
| HEI | Higher Education Institute |
| HDI | ‘Historically Disadvantaged Institution’ |
| SAIP | South African Institute of Physics |
| SER | Self-Evaluation Review |
| SACMEQ | Southern and East African Consortium for Monitoring Educational Quality |
| FTE | Full-Time Equivalent (student) |
| WIPISA | Women in Physics in South Africa |

# 1. Background to the Review

## 1.1 Rationale for review of undergraduate Physics

Impetus for this review of undergraduate Physics education at higher education institutions in South Africa originated from within the Physics community itself. However, the issues at stake go far beyond the interests of this community in that they are intimately connected with matters of national interest.

The report begins with a brief overview of concerns both from within the Physics community and from the broader perspective of national interest.

### *1.1.1 Review initiatives from within the Physics community*[1]

Internal pressure for a review aimed at improving teaching and learning in Physics is not a recent phenomenon.

An earlier combined initiative involving the Department of Science and Technology, the National Research Foundation, and the South African Institute of Physics (SAIP)[2] resulted in a report *Shaping the Future of Physics in South Africa* (April 2004). In this report the task team consisting of local and international experts made a series of recommendations related to the sustainability of physics in South Africa. The panel noted that though the South African physics community is small, it enjoys a good international reputation, and exhibits significant strengths in certain areas. It noted the resilience of the physics community in attempting to address structural problems experienced in recruiting and retaining students, as well as coping with numbers of under-prepared students.

At the SAIP annual meetings in 2008 and 2009, Heads of Physics Departments across the higher education sector reiterated their concerns about the poor quality of the entering students and their inability to master physics of an appropriate standard. Lack of preparedness, they argued, had consequences for the quality of Physics graduates completing their first degree and entering postgraduate study. The SAIP Council responded by initiating a project that has come to be known as "Review of Physics Training in South Africa". This project proposed to:

- develop a set of standards for physics training in South Africa;
- assess levels of commonality and diversity of the physics programmes;

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[1] Data in this sub-section are drawn from the document: *Physics Project Proposal: Draft for Circulation. 22 March 2012.*

[2] The non-statutory professional body, SAIP, has a membership of approximately 500 physicists
[2] The non-statutory professional body, SAIP, has a membership of approximately 500 physicists
and defines its mission as the voice of the discipline of physics in South Africa. Its objectives include promoting study and research in physics and related subjects as well as encouraging its application.

- assess range, scope and effectiveness of current teaching and learning practices in physics at universities;
- identify best practices that can inform pedagogic innovation;
- develop a set of contextually appropriate recommendations which would have the effect of improving the effectiveness of physics teaching at the universities.[3]

This project focuses on providing an analytical and critical self-appraisal of undergraduate physics teaching and learning across South African public higher education institutions.

### *1.1.2 Implications of the Ten-year Innovation Plan and 2012 Green Paper*

The present review into undergraduate physics education in part flows out of recommendations emanating from *Shaping the Future of Physics in South Africa Report* (April 2004). Amongst the recommendation made were ones dealing with (a) the state of teaching science in secondary schools, (b) attracting and retaining good physics teachers, and (c) university throughput; all of which have a bearing on undergraduate physics education.

In 2007 the DST produced their *Ten-Year Innovation Plan* which aims to steer South Africa's '*resource-based economy towards a knowledge-based economy*[4]'. The plan noted that '*the level of economic growth envisaged by our country requires continual advances in technological innovation and the production of new knowledge'*. To achieve this, the *Ten-Year Innovation Plan* set the goal of a dramatic five-fold increase in PhDs in Science, Engineering and Technology.

Subsequently the Department of Higher Education and Training produced the *2012 Green Paper* which sets out their vision for the post-school system in South Africa. It seeks to align the post-school education and training system with the societal and economic needs of the country. In this vision, growth paths for all post-school educational institutions are linked to government's development agenda as expressed in key policy and strategy documents, such as the DST's *Ten-year Innovation Plan* of 2007.

> The Department of Science and Technology's *Ten Year Innovation Plan* states that the level of economic growth envisaged by our country requires continual advances in technological innovation and the production of new knowledge … According to the *Ten Year Innovation Plan,* South Africa's PhD production must grow dramatically, with a five-fold increase in PhDs in Science, Engineering and Technology" (2012 Green Paper, p. 13).

The Green Paper also nuances its target with the issue of demographic profile: "… blacks and women students continue to be under-represented in science, engineering and technology …" (2012 Green Paper, p. 8).

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[3] Physics Project Proposal: Draft for Circulation. 22 March 2012.

[4] Department of Science and Technology. 2007. *Ten-Year Innovation Plan.*

Clearly such a dramatic increase in PhDs can be met only if there is a corresponding increase in the number and quality of undergraduates emerging from the HEIs. Viewed in numerical terms alone, the number of students successfully completing undergraduate and honours degrees in Physics increased between 2001 and 2009.[5] The number of Physics graduates between these years increased from 88 to 117; and the number of honours graduates from 41 to 98. Impressive as this rate of increase is, it clearly needs considerable acceleration if the Green Paper's vision of aligning post-school education and training with the country's societal and economic needs are to be met. Furthermore, it cannot be assumed that even the successful honours students are necessarily equipped for PhD study.

## 1.2 The Review as a collaborative CHE/SAIP project[6]

Through Professor Edmund Zingu, the SAIP approached the Council on Higher Education (CHE) to undertake a collaborative review of teaching and learning in undergraduate Physics.

This project of reviewing undergraduate Physics education is a novel exercise within the South Africa higher education context. Though it focuses on a discipline, it concentrates on improving the teaching and learning therein. It is concerned about curriculum details only insofar as it promotes or hinders teaching and learning practices. For the CHE, this was a departure from the established practices of the National Reviews Directorate of focusing on *programme* rather than on *disciplinary* reviews. The SAIP proposal however resonated with the CHE's understanding that physics, like many other disciplines, faces challenges of sustainability and often relies on teaching 'service' courses to improve its financial viability. As such, the CHE agreed to facilitate the review as it regarded this project as resonating with its recent mandate of developing standards and saw this as an opportunity to contribute to it.

The national importance of physics in fulfilling its essential role in the economic development of the country and the African continent, allied to the general demand for physicists, makes the discipline an indisputable scarce skill. This is further corroborated in the *National Development Plan -2030* as one of the key priorities that concern the improvement of the quality of education, skills development and innovation and which are part of the key thrusts of this project.

The CHE accordingly responded to the SAIP proposal by making its expertise, review experience and infrastructure available. In a series of meetings, fruitful co-operation between the physics community and the National Reviews Directorate led to the developments and decisions that guided the review, as outlined below.

[5] Physics Project Proposal: Draft for Circulation. 22 March 2012. The rate of increase is, however, uneven across institutions. The Regional Meeting held in Gauteng reported dwindling numbers of Physics majors.

[6] Data in this sub-section are drawn from the document: Physics Project Proposal: Draft for Circulation. 22 March 2012

It must be emphasized that although this report is produced under the auspices of the CHE, the review on which it was based was not a function of the CHE: conceptually and operationally, the review was 'owned' by the SAIP and the Physics community.

# 2 REVIEW PURPOSE

## 2.1 PURPOSE OF THE REVIEW

Formally, the purpose of the review was expressed as follows:

> In light of the concerns expressed by the Heads of Physics Departments regarding student competence, to consider the extent to which teaching and learning delivers graduates with the knowledge and skills which would maximize their potential to pursue postgraduate studies and other employment careers. The review will provide advice on possible strategies to enhance physics teaching and learning.
>
> In addressing this purpose, the review will focus upon the role played by the various physics departments and how best practices could assist those which are challenged in various aspects of their operations.[7]

## 2.2 THE GROUP OF EXPERTS AND TERMS OF REFERENCE

A Group of Experts (see Appendix A) was charged with responsibility for providing a status report of undergraduate physics teaching and learning in South Africa; and making recommendations for its enhancement. Its task was to consider:

- the different approaches to physics teaching by the departments
- resources available for undergraduate physics teaching
- the value of skills developed by students
- the potential of the physics training system to assist students in achieving personal objectives
- the potential of the physics training system to assist students to achieve national objectives
- the strengths and weaknesses of different elements of physics teaching strategies
- the role of student habits and participation in maximizing physics learning.[8]

Clearly, the focus of the review was firmly on the *teaching and learning* of undergraduate Physics. Curriculum *content* was notably excluded from the purview of the review. This is because Physics is a universal discipline: content is largely a 'given' and all universities are more or less aligned with the 'international' curriculum. In particular, the universality of curriculum content was confirmed in responses to the departmental self–evaluation review (SER) question: "How current is the content of

[7] Review of Undergraduate Physics Teaching and Learning. Group of Experts Terms of Reference.

[8] Ibid.

your theoretical and laboratory courses? How do you establish whether a course or module is current?" Examples of responses are:

- We look to other leading universities to benchmark our courses and to motivate our choices of prescribed books. In the case of the laboratory course, we have looked to internationally accepted measurement standards for direction (e.g. GUM).[9] (University of Cape Town)
- There is something of a 'national expectation' of what should be offered in a university level first, second and third year Physics course, and we would not wish to deviate from that and risk being labelled as not being 'up to standard' by our fellow institutions. ……Occasionally the Physics Department compares the content of our current syllabi with international curricula. (University of Fort Hare)
- A Google search of the courses run at various international universities helps in determining the current international trends, as does interrogation of curricula when on sabbatical visits to overseas departments. … . (University of KwaZulu-Natal)
- Courses are evaluated by benchmarking them against other institutional offerings to establish their currency. (University of Zululand)

Hence, the focus of the present review is on the teaching and learning processes through which students are inducted into the internationally accepted standards that shape specification of the knowledge and skills undergraduate Physics students should master.

# 3 REVIEW METHODOLOGY

## 3.1 DATA FOR THE REVIEW

In meeting its Terms of Reference, the Group of Experts was able to draw on earlier review documentation – particularly in the form of a Benchmark Statement – in addition to data generated specifically through collaborative CHE/ SAIP effort.

### *3.1.1 BACKGROUND DATA: BENCHMARK STATEMENT ON ATTRIBUTES OF PHYSICS GRADUATES*

The first phase of the project - prior to collaboration with the CHE - consisted of the development of a 'Benchmark Statement for Physics' that, along with the BSc Qualification Registration Statement, represent the minimum standards for undergraduate training in Physics. The Draft *Benchmark Statement for Physics in South Africa* was completed in 2011. It characterizes the skills and achievements that graduates of physics-based degrees should develop, and includes a core curriculum (approximately 50%) for undergraduate physics. The statement specifies that students in physics *should* learn:

- How to formulate and tackle problems in physics. For example, they should learn how to identify the appropriate physical principles, how to use special and limiting cases and

[9] Guide for Uncertainty in Measurement

order-of-magnitude estimates to guide their thinking about a problem and how to present the solution, making their assumptions and approximations explicit;

- How to use mathematics to describe the physical world. They should have an understanding of mathematical modelling and of the role of approximation;
- How to plan, execute and report the results of an experiment or investigation. They should be able to use appropriate methods to analyze their data and to evaluate the level of its uncertainty. They should also be able to relate any conclusions they make to current theories of the physics involved;
- How to compare critically the results of model calculations with those from experiment and observation. [10]

The Draft Benchmark Statement further suggests that a physics degree should enhance the following types of *skills:*

- *Problem-solving skills* - physics degree programmes involve students in solving problems with well-defined solutions. They will also gain experience in tackling open-ended problems. Students should develop their ability to formulate problems in precise terms and to identify key issues. They should develop the confidence to try different approaches in order to make progress on challenging problems.
- *Investigative skills* - students will have opportunities to develop their skills of independent investigation. Students will generally have experience of using textbooks, and other available literature, of searching databases and the Internet, and of interacting with colleagues to derive important information.
- *Communication skills* - physics and the mathematics used in physics deal with unexpected ideas and difficult concepts; good communication is essential. A physics degree should develop a student's ability to listen carefully, to read demanding texts, and to present complex information in a clear and concise manner.
- *Analytical skills* - physics helps students learn the need to pay attention to detail and to develop their ability to manipulate precise and intricate ideas, to construct logical and reasoned arguments and to use technical language correctly.
- *ICT skills* - during their studies, students will develop their computing and ICT skills in a variety of ways, including their ability to use appropriate software such as programming languages and analysis packages.[11]

### *3.1.2 DATA GENERATED THROUGH THE REVIEW*

In compiling the present report, the Group of Experts (hereafter 'The Group') had access to three sources of data: departmental self-evaluations; reports of regional meetings; and responses to a student questionnaire. Detail on each is provided below.

[10] *CHE-SAIP Review of physics undergraduate education. Discussion Document.* June 2012.

[11] Ibid.

#### *3.1.2.1 Self-evaluation within Physics Departments*

**The self -evaluation instrument**

An online self-evaluation report (SER), completed by 20 Departments of Physics, was central to the assembly of baseline data.

The SER questionnaire was constructed on the basis of intensive interaction between Professor Zingu, heads of Physics Departments, and the collaboration of the CHE National Reviews Directorate. In these discussions the Higher Education Qualifications Committee (HEQC) accreditation criteria on teaching and learning were found to be a useful resource for developing Physics-specific issues into individual questionnaire items.

Questionnaire items covered 126 questions organized into 12 sections (for detail of the 12 sections, see Appendix B). In the three types of questions presented, Departments were

- asked to rank the importance of specific learning activities that contribute to the development of specific skills required in physics;
- asked to respond to a range of questions;
- invited to upload data in support of their responses.[12]

**Response to the review from the Physics community**

The SER elicited an excellent response, evident in:

(a) the participation of all but two Universities of Technology in review meetings;

(b) submission of the Departmental SER and Student Survey on the part of
- 4 of the 6 Universities of Technology
- 12 of the 13 Universities
- 4 out of 4 Comprehensive Universities;[13]

(c) all but one of the participating institutions also uploading supporting documents.

Participation is summarized in Table 1 below.

[12] http://physicsreview.ezi.co.za/index.php/analysis-report/departmental-reports

[13] The full list of these universities is provided in Appendix C.

**Table 1: Participation of the Physics community in Review procedures**

| **Type of Institution and total number** | **Participated in Review meetings** | **Submitted Departmental SER** | **Submitted Student Survey** | **Uploaded supporting documents** |
|---|---|---|---|---|
| Universities of Technology (# = 6) | **4** (67%) | **4** (67%) | **4** (67%) | **3** (50%) |
| Universities (# = 13) | **13** (100%) | **12** (92%) | **12** (92%) | **12** (92%) |
| Comprehensive Universities (# = 4) | **4** (100%) | **4** (100%) | **4** (100%) | **4** (100%) |
| **Total** (# = 23) | **21** (91%) | **20** (87%) | **20** (87%) | **19** (83%) |

### *3.1.2.2 Regional discussions*

Physics academics met in four regional clusters to discuss key issues. The table below indicates the attendance of the institutions at the four regional clusters.

**Table 2: University representatives participating in regional cluster meetings**

| **Northern Region** | **Western Cape** | **Eastern Cape** | **KwaZulu Natal** |
|---|---|---|---|
| University of the Witwatersrand *(Host)* | Stellenbosch University *(Host)* | Nelson Mandela Metropolitan University *(Host)* | University of KwaZulu-Natal *(Host)* |
| University of Johannesburg | University of Cape Town | Rhodes University | Durban University of Technology |
| North-West University | Cape Peninsula University of Technology | Walter Sisulu University | Mangosuthu University of Technology |
| University of the Free State | University of the Western Cape | University of Fort Hare | University of Zululand |
| University of Venda | | | |
| Tshwane University of Technology | | | |

Regional meetings were an opportunity for institutions to exchange experiences - positive and challenging ones - regarding undergraduate Physics education. These events also provided an opportunity for Departments to raise issues in connection with the SERs they had recently completed.

Reports of proceedings were drawn up and made available to the Group.

#### *3.1.2.3 STUDENT PERSPECTIVES*

An online questionnaire was constructed to elicit student views on their experiences in studying undergraduate Physics. Each Department was requested to invite twenty "reliable"[14] students across the various years of study to participate in the online Student Questionnaire. The maximum number of respondents from the 20 participating institutions would have been 420. In the event, 218 students provided thoughtful, detailed responses. As there was no follow-up pressure on non-respondents (because the student response was regarded as free and democratic gesture) the 52% return rate can be interpreted as a serious commitment on the part of the students to contribute their experiences and perceptions of learning Physics.

The resultant sample represents a good spread of students from urban and rural HEIs, albeit with a sample that is somewhat skewed in two respects.

**First**, the sample is skewed in favour of first-year students. Actual numbers are: [15]

- First-year students: 94
- Second-year students: 56
- Third-year students: 44
- Honours students[16]: 21

Experience suggests that junior students do not generally have enough experience and self-reflection to provide sufficiently meaningful responses to probing evaluation questions. Upper level and graduating students have been found to provide more useful responses.[17] On the other hand, in the present case, the enthusiasm of the first-year student response was noteworthy. They may not yet have acquired enough Physics experience to comment *reflectively* on the quality of Physics teaching and learning, but by the time they completed the student survey they would have almost completed their first year of study. Their insights were accordingly respected as such.

**Second**, the method of recruiting students to respond to the Student Questionnaire resulted in a sample that is very likely to be over-representative of the most academically strong students. This issue is discussed under 3.2 below.

[14] "Reliable" in the sense that they would be likely to devote the time required to produce thoughtful responses to all question.

[15] The total below is 215. Three of 218 respondents did not provide a clear indication of their year of study.

[16] Technically, Honours students lie beyond the review focus on undergraduate Physics. However, Honours students were included in the sample because of their potential to provide an overall view of their undergraduate experience. They were incorporated as a *groupe de temoignage* – a group of testimony.

[17] Professor Carl Wieman, personal email communication to Group of Experts (1/2/2013).

## 3.2 DATA ANALYSIS: GROUP OF EXPERTS *MODUS OPERANDI*

**Data sources**

Against the backdrop of the Benchmark Statement (3.1.2 above), the Group engaged with three sets of data. They worked with data (a) derived from the Departmental SERs (b) student questionnaires, and (c) from the regional meetings.

The SERs and the student questionnaires constituted the core, structured data for analysis. The Website http://physicsreview.ezi.co.za, designed to be the entry point to the Review of Undergraduate Physics Teaching and Learning in South Africa, afforded the Group exclusive access to all these data and related information.[18]

**Process of formulating key issues**

A workshop was considered the ideal method for the Group to interact with and analyse the data. The Group began its task by working systematically through cognate sections from all SERs. Members in the Group had earlier been assigned the responsibility of analysing allocated sections of the SER according to identified key questions. Each member then led the discussions on the section allocated to him/her. At the end of the discussion on each of the identified questions, significant points were formulated and summarized (for examples, see Appendix B). From the identified significant points, consensus was sought on the key issues emerging from the data. In this way the Group worked through the evaluation data, key question by question. The Group then analysed the data from the Student Questionnaire. All discussions emanating from the data were recorded and notes were used to review and reflect on key issues.

**Consolidating review data for purposes of making recommendations**

Recommendations that had begun 'emerging' during the course of identifying the main issues were consolidated into a set of recommendations as part of the outcomes of the Group's workshop.

Recommendations were finally specified only after 'emerging' formulations had been weighed against other data. This process involved the Group looking for consistencies and patterns in responses from the SER and Student Questionnaire. While all data were respected, none were accepted uncritically or at face value. Thus the Group made critical judgements in light of:

- the widely accepted limitations of self-report data and questionnaires;
- other relevant sources of evidence, such as the regional meetings;
- the combined experience, expertise and scholarship within the Group.[19]

In so doing, the Group was faced with what at first appeared to be a problematic inconsistency between the views of academics in the SERs compared with perceptions

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[18] http://physicsreview.ezi.co.za/index.php/about-the-website

[19] The Group also had the benefit of the inputs and support of two prominent international experts in Physics education (see Acknowledgements).

evident in the Student Questionnaire. In short: SERs made for generally sombre reading, while responses to the Student Questionnaire presented a far more optimistic picture of success in teaching and learning. The Group understood this seeming disjunction as a consequence of a key difference between the two samples:

- **SERs:** This sample represents the departmental views of 20 of the 23 universities in South Africa (see section 3.1.2.1). SERs were based on consideration of *all* students in undergraduate Physics programmes (i.e. students across the *entire spectrum of ability*). SERs were dominated by accounts of departmental endeavours to meet the learning needs of the inadequately prepared students they were teaching.

- **Students:** Available evidence strongly suggests that respondents to the Student Questionnaire, having been selected because they were "reliable"; also happened to be the top academic students. Student responses accordingly presented the very strong impression of being the utterances of those who had been well prepared for the study of Physics, and who were appreciative of the quality of the course and the commitment of their teachers. A good, solid 'traditional' course consequently met *their* learning needs. The voice of the struggling student was barely, if at all, evident in the sample of 218 students.

On the other hand, while **SER** data presented as being somewhat constrained by the inherent constraints of questionnaire methodology (and, possibly also, by the public gaze into internal departmental affairs), the **Student** data could more certainly be regarded as the uninhibited voice of students.

With the two sets of data thus presenting different levels of representivity and validity, the Group scrutinized and interpreted each on its own merits.

**'Member Checking'**

The first draft of this report ultimately went through a process of 'member checking'.[20] In the interests of the validity of the final account, members of the Group of Experts scrutinized and commented on the draft.

# 4. CONSOLIDATED SET OF ISSUES TO INFORM RECOMMENDATIONS

Issues to inform recommendations are structured as follows:

- Section 4.1 presents the over-riding theme to emerge from departmental self-evaluation: students are under-prepared for undergraduate Physics. This view

[20] The term widely used for the process of checking data, analytic categories, interpretations and conclusions with members of the groups from whom the data were originally obtained.

is supported by objective accounts of poor student performance in Physics from school through to undergraduate Physics.

- Drawing on Physics departments' self-evaluations, section 4.2 provides an account of departmental responses to the under-preparedness of undergraduate physics students. It will be seen that departments have focused on innovation in teaching and student support rather than in forms of student assessment.
- Section 4.3 provides a student perspective based on the Online Survey. This sample of largely successful Physics students shows appreciation for the teaching and support they have received. However, absent in the survey data is the voice of the many students whose under-performance is so clearly evident in section 4.1.
- In section 4.4, data from the departmental self-evaluations are used in covering a range of other issues relevant to supporting and improving undergraduate Physics.

## 4.1 From school to undergraduate Physics: Student performance

### *4.1.1 School leavers present teaching and learning challenges*

The powerful and visible thread running through the departmental SERs was the conviction that school leavers are inadequately prepared for undergraduate Physics. This was most evident in students' lack of adequate mathematical and problem-solving skills. On this issue, the departmental sample yielded no dissenting voices. The following examples drawn from the SERs provide some insight into the nature and scale of the problem related to student preparedness.

The first two examples consider the lack of mathematical skills as a major impediment in learning Physics.

> One of the major challenges faced by the Department in the last 5 years is the level of preparedness of the first-year students. One of the major causes of this is the mathematical skills of these students, which in our opinion is as a result of changes that have taken place in the national high school Mathematics curriculum with the abolition of the HG/SG[21] system and the introduction of Maths Literacy and Mathematics. Maths Literacy is not accepted as adequate for preparing students for studies in the exact Sciences, but it is found that even NSC[22] Mathematics does not adequately prepare students for Physics because very crucial topics such as Geometry and logarithms that are critical are not being covered.

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[21] In the belief that learners would benefit from being with others of their own levels of ability and development, the former education system channelled senior students into 'Higher' (HG) and 'Standard' (SG) ability streams.

[22] 'NSC' is the National Senior Certificate, the new school-leaving certificate introduced in 2008, in which all Subjects are all taken on the same level. There is no 'Higher' or 'Standard' grade as in the past.

> Our [Physics Department's] biggest problem is the under-preparedness of incoming first year students. Many of such students are lacking in basic mathematical skills (such as trigonometry, analytic reasoning and basics problem solving strategies), presumably due to a failing at school level. We are then left with the dilemma that if we "dumb-down" the course too much we short change the top students who are there to carry on with Physics and plan to major in it; whereas if we cater to these top students the ones at the bottom are completely lost and drop out (our second problem).

The next example considers the new school curriculum as inadequate in preparing students for undergraduate Physics.

> Like physics departments all over the country, our department has noticed a drop in school-leaver preparedness due to the new school curriculum. Although students have been introduced, at school, to more material than learners taught according to the old curriculum, this comes at the expense of a deep understanding of the fundamentals. In particular, we have noticed poor vector skills, a lack of geometric and visualisation skills, and generally poor algebraic manipulation skills.

The last two examples consider the effects of the large increase in student numbers on the need for departments to prepare students for undergraduate study and the burden it places on them to find appropriate teaching and learning methodologies.

> The massive increase in student numbers coupled with the decreased skills and preparedness of the student body has been the most challenging aspects over the last 5 years.

> Progressively lower levels of preparedness and background from school learners; lecturers spend more time introducing e.g. tutorial / remedial classes. Larger numbers of students made it prohibitive.

Lack of preparedness also manifested itself in what might be termed 'secondary' issues. Few students showed understanding of plagiarism, but because of pressure of time to deal with fundamentals, only three Departments reported on attempts to teach courses on ethics.

A small number of students also referred to lack of preparedness - but more obliquely, in the form of references to 'other' students and their ability to do Physics.

At the exit level of schooling, according to the South African Institute of Race Relations (SAIR), the proportion of students achieving a pass in Mathematics of between 70% and 100% has fallen to 5.9% from 8.3% in 2008. Only 20% of matriculants achieve more than 50% in Mathematics and Physical Science.[23] Commenting on the controversial 30% pass mark, the SAIRR notes that if the pass mark were to be improved to 50% in line with university standards, the real rate of failure for mathematics and physical science would be closer to 80%.

In the words of one member of the Group, lack of student preparedness "is not a problem – it's a given".

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[23] http://www.sabc.co.za/news/a/55ce55004e5c358c8491b7f251b4e4e2/Only-20-of-maths,-physics-matriculants-exceed-50-pass-mark:-SAIRR-20132901 Tuesday 29 January 2013 17:30.

### 4.1.2 LACK OF PREPAREDNESS – A UNIQUELY SOUTH AFRICAN PROBLEM?

At the same time as noting the depth of departmental concerns, the Group was aware of reports and research from many other parts of the world identifying this very same challenge. In this sense, the problem in South Africa is not unique.

However, in addition to the objective evidence cited above, there is also hard evidence showing that the level of under-preparedness is *substantially worse* in South Africa than in almost all other countries.

Arguably the most respected research on students' educational achievement in schools across borders is provided by the Trends in International Mathematics and Science Study (TIMSS). TIMMS has been conducting standardized tests[24] every four years since 1995. The *TIMSS 2011 International Results in Mathematics*[25] and *the TIMSS 2011 International Results in Science*[26] summarize fourth and eighth grade student achievement in each of the 63 countries and 14 benchmarking entities which participated in the study.

The scope of the present report is too limited to permit detailed coverage of TIMMS findings in 2011. However, the appalling comparative performance of South African school students is captured in the following findings.

(a) Because the TIMMS grade 8 assessment was found to be too difficult for Grade 8 students in three countries, the tests in both Mathematics and Science were administered in Grade 9 instead. These three countries were Botswana, Honduras, and South Africa.[27]

(b) "… there was evidence of many very low performing ninth grade students in all three countries, with the percentage of students with achievement too low for estimation exceeding 25 percent in South Africa and Honduras and between 15 percent and 25 percent in Botswana." [28]

(c) The average scale score of South African Grade 9 students writing the Grade 8 test was lower than that of 41 of the 42 countries whose students wrote the Grade 8 test. Here, South Africa was ranked above only Ghana. Of the three countries whose Grade 9 students wrote the Grade 8 test, South Africa is ranked above Honduras, but below Botswana.[29]

The picture of the performance of South African grade 9 students in Science is, if that were possible, marginally worse. Compared to the 42 countries writing the Grade 8

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[24] developed by developed by the International Association for the Evaluation of Educational Achievement (IEA).

[25] http://timss.bc.edu/timss2011/international-results-mathematics.html

[26] http://timss.bc.edu/timss2011/international-results-science.html

[27] *TIMSS 2011 International Results in Mathematics*, Chapter 1, p.8.

[28] Ibid. p. 50.

[29] Ibid. pp. 42-43.

TIMMS test, South Africa emerged ahead of only Ghana; but of the three countries whose Grade 9 students wrote the test, it was below both Botswana and Honduras.

It is true that the TIMMS sample includes most of the developed countries, and few of the least developed. Nonetheless, the performance of South African students is hardly better than that of our poorer neighbours. The Southern and East African Consortium for Monitoring Quality Education (SACMEQ, 2000) scores for Grade 6 Mathematics ranks South Africa above only Lesotho, Malawi, Namibia, Zanzibar and Zambia. The eight countries ranked by SACMEQ above South Africa include Botswana, Swaziland and Botswana.[30]

> Clearly the South African primary school system is significantly underperforming relative to its regional counterparts given its large relative advantage in material resources.[31]

Notable improvement in school leavers' proficiency in mathematics and science will not come easily. An old adage tells us that "Teachers cannot teach what they don't know". SACMEQ finds that teachers do not know much mathematics:

> Mathematics teachers are battling with simple issues such as calculating percentages, according to a study using the recent Southern and East African Consortium for Monitoring Educational Quality (SACMEQ III) dataset for South Africa. [32]

The National Education Evaluation and Development Unit (NEEDU) progress report to the Parliamentary Monitoring Group expressed the situation thus:

> The majority of schools in this country were not being held back through poor discipline, but because our teachers did not have the requisite knowledge. In the SATMEC tests in 2010 teachers were also tested on their knowledge and results for teachers in Grade 6 showed that they did fairly well in arithmetic operations but fell below 50% when the mathematics became a little more complex, and achieved an average of 52.39% overall. Similarly in language teachers did well in retrieving but for inference, interpretation and evaluation they did extremely poorly. If a teacher could not exercise those things herself how could she teach it?[33]

While comparative tests might be criticised for methodological bias, it is clear that the performance of South African learners in mathematics and science is consistently appalling across tests administered by different bodies. This dire situation is most starkly apparent in the most recent World Competitiveness Report (2012-13) issued by

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[30] Taylor, N. (2009) The state of South African schools Part 1: Time and regulation of consciousness. *Journal of Education,* no. 46, p. 10.

[31] Spaull, N. A. Preliminary Analysis of SACMEQ III South Africa. Stellenbosch Economic Working Papers: 11/11: p. 24. Accessed from www.ekon.sun.ac.za/wpapers/2011/wp112011/wp-11-2011.pdf *(11/2/2013)*

[32] Accessed from http://mg.co.za/article/2011-04-04-teachers-maths-problems-just-dont-add-up (11/2/2013)

[33] Accessed from http://www.pmg.org.za/report/20130226-department-basic-education-inclusive-education-national-education-eva (12/5/2013).

The World Economic Forum.[34] On the "quality of its educational system", South Africa is ranked 140th out of 144 countries; and in Mathematics and Science, 143rd (ahead of only Yemen).

This is the reality each Department of Physics faces regarding the capacity of students to do Physics.

### 4.1.3 *STUDENT WORK ETHIC*

Compounding the challenge of unprepared students is their reported lack of serious work ethic. Again, all Departments raised this problem in different forms: students don't attend lectures, don't hand in homework, don't spend sufficient time on their subject, and so on. Several cases were cited of the very students for whom extra tutorials or learning opportunities had been organized, not utilizing those advantages. Typical statements referring to challenges regarding student participation in supplementary teaching and learning efforts include the following:

> These sessions, referred to as the Academic Development Program (ADP) offers first year students to meet with tutors and raise and seek help on specific academic areas of concern. Unfortunately, we only have the resources to run ADP for the first years. Some students also don't seem to make use of the ADP sessions as we would expect.

Students may have different perceptions about studying at University. As the citation below demonstrates, it is the outcome rather that the process of acquiring knowledge that seems to interfere with the learning of Physics.

> Another source of increased frustration in the last five years has been an increasingly negative student attitude towards study and knowledge accumulation, coupled with a belief that the only thing that matters is graduating, without regard of how one gets there (this is probably a current world-wide phenomenon triggered by the materialism of the early years of this century). Students are more concerned with 'beating the system' by monitoring exam question setting trends, etc. than internalising skills and knowledge critical to their success in their future work environment.

The remark below demonstrates the importance of a balanced workload in promoting an environment conducive to the teaching and learning of Physics. Organising tutorials and other activities to assist students in interacting with Physics requires a committed effort from students as well.

> Students do up to 5 courses/subjects per semester with very full time tables and very little time for tutorials and self-study. Tutorials in many instances are therefore conducted on a Saturday, and attendance is a problem.

Some support for departmental views is evident in a small number of responses to the Student Questionnaire. Identifying areas of difficulty, one student wrote:

"The general nature of what Physics IS makes it difficult. There is nothing that should be easy about physics at 3rd year level, and I don't expect anything 'easy'. That, in itself is the beauty of the study of the physical."

[34] http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf , pp. 442 - 443. (12/5/2013).

However, the solution to the difficulty was:

"Dedication to this field of study will be what overcomes the laziness plagued by modern students." In similar vein, a second-year student's 'solution' was simply: "Study. Study passionately."

Interpreting these and other responses, the Group could not but accept the fact that many students were not keeping pace with what the study of physics and departmental academic support demanded of them. However, reasons for the problem could be complex, as many factors may give rise to what appears to be, or manifests, as a poor work ethic. The third departmental statement above, for example, draws attention to the fact that the workload demanded of students is very considerable. It is also possible that students may not know, for example, *how* to learn. Or their skills of time management may be poor. Further research would be needed to explain reasons for what is an incontestable problem: many students do not keep up with the required work rate.

### *4.1.4 Effect of Preparedness on Pass Rate and Throughput*

The objective picture of student under-preparedness as it emerges in 4.1 and 4.2 has predictable consequences.

Analysis of the data supplied by Departments show a wide range of student pass rates, varying from the mid-50% all the way up to 100%. In general the pass rates were lowest for 1st-year students, particularly for first semester students, and highest for 3rd-years, as one might have anticipated. At some institutions the low pass rates continued into second year indicating that their students found the transition from the general, entry level physics to the more in-depth, senior level physics difficult, while other institutions appear to handle the transition better.

There was no obvious explanation for the wide variation in reported pass rates, with departments from both HDIs and previously 'white' institutions amongst those reporting the lowest pass rates, and also those the highest. Pass rates in the mid-50s are clearly consistent with poorly prepared students struggling to meet the demands of tertiary education, roughly what one would expect given the intake. On the other hand, pass rates in the high 80s / low 90s achieved by some HEIs are indicative of 1st-year students who are coping extremely well. Given the manifest under preparedness of students entering the institutions it is difficult to understand how 1st-year pass rates at this high level are achievable, particularly as the higher pass rates did not always correlate with those departments most deeply involved in innovative teaching practices.

It should be noted, however, that there is often no indication of how the pass rates are determined. Some institutions appear to calculate the pass rate base on those students eligible to write the final exam (i.e. excluding the students who dropped out during the course and also those who did not perform well enough to be entitled to write the final exam), while others appear to have determined it on the number of students originally registered for the course. This may go some way to explaining the wide variation in the observed pass rate, but it cannot be the only cause, and it is more likely that the variation is a reflection of the way in which the courses are examined, rather than on the ability of the students to master the material. The initial indication of a problem with undergraduate physics education arose from Heads' complaints concerning the quality of students entering the honours programme. This suggests that, in some instances, the lack of preparedness of incoming students is possibly being managed by the adjustment of standards rather than by setting the appropriate level and then managing the devlopment of students up to that level by best teaching methods. This is of great concern to the Group as debasing the standard of the degree is in neither the interest of the student nor the institution awarding the degree.

Pass rates clearly have a direct impact on throughput. First-year students are probably taking the equivalent of four full-year courses, so even with a pass rate of 80% one can expect that 40% or more students will fail at least one course at first year. If the course is not a prerequisite for any of their second year subjects, the weak student will then try to carry the 1st-year subject together with a full 2nd-year load, and inevitably fail again the following year. A detailed study undertaken by one institution tracking the progress of students who enrolled for their B.Sc. over the period 1995 – 2002 showed that only 35% of the students obtained their B.Sc. within three years, and that on average only 56% of students eventually obtained their B.Sc. (with a further 9% graduating in other faculties).[35] These numbers are roughly in line with those obtained by the CHE[36] which reports that of all students registering for a degree in Life or Physical Science at an HEI (other than UNISA) in 2000, only 47% graduated within 5 years, and with only a further 13% still registered for the degree this indicates that 40% of the students had dropped out without obtaining a degree.

Clearly there will need to be a drastic improvement in the pass rates and throughput in degrees of a high quality if we are to meet the five-fold increase in PhDs envisaged by the DST and the DHET.

## 4.2 Departmental responses to the challenge of teaching undergraduate Physics

In response to the challenges around the teaching and learning of Physics, Departments have made structural changes and adopted innovative modes of teaching Physics. Such modes represent a departure from the traditional style of lecturing intended for students already displaying a mastery of basic skills required.

### *4.2.1 Innovations in teaching and student support*

Extensive use is made of foundation programmes (i.e. designed to better prepare students for entry into higher education), extended programmes (i.e. where the qualification is taken over an extended period, for example by covering 1st-year material during the first two years) and special tutorials, as exemplified in the following five accounts that range from identifying students-at-risk to designing first-year Physics programmes with the challenges in mind.

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[35] Study undertaken by the Science Faculty at UCT

[36] HE Monitor No 6, 2007

> We have introduced extra tutorials, especially at the first-year level, and have a system of hot-seat tutors where graduate students are available to assist students with difficulties encountered during their self-study.
>
> The University supplied funding to support supplemental instruction tutors.
>
> Dealing with underprepared students: These are selected using placement tests together with NSC results and the available seats (15 % of new intake) are filled. They are channelled into the 4 year extended BSc programme where foundational skills are incorporated into content coverage.
>
> This period has also led to the intensification of the 4-year BSc Extended programmes. These were introduced about 10 years ago to enable talented but badly prepared students from disadvantaged schooling backgrounds an entry into university. The idea was that these programmes were supposed to involve smaller class sizes, additional tuition and better support for a limited number of rigorously selected students. Unfortunately, at our institution, it has become a means of boosting numbers (and subsidy) and allowing students from privileged schools with poor matric marks into the system. There are now 300 students doing PHY1A1E (the first semester of Physics 1 for Extended students), and 200 doing PHY1A2E and PHY1A3E (the corresponding second and third semester courses). Each of these is divided into three classes, resulting in class sizes too big for personalised attention. Splitting the classes even further is not an option due to the impossible strain this would place on our teaching staff resources.
>
> Almost all institutions have some form of extended curriculum to accommodate different levels of student competency. Generally the 1st experience is split over two years and students then expected to enter mainstream physics. The discussion of a 4 year programme has become an institution-wide discussion. If the programme is too slow, there is a real risk of losing good students (from Notes of the Western Cape regional meeting).

Other institutions have introduced or increased their use of technology for delivery and course management, sometimes together with new pedagogical techniques for increasing social interaction. Some innovations merge these approaches with tutorial support. The examples below demonstrate the different techniques in promoting an interactive Physics environment.

> We now include more interactive engagement activities in lecture-classes; we set pre-reading activities for students to prepare for classes, and we make more use of educational technology (eg. physics simulations, online video clips etc). We encourage senior undergraduate students to attend departmental colloquia. We foster students' exposure to physics research through visits, talks and outings.
>
> [At our institution] tutors are available for consultation, so that students are given support in their learning. In addition, all mainstream courses have "whiteboard tutorials" in which groups of 2-3 students solve problems on a whiteboard with lecturers and tutors roaming the venue. In this way, students are guided in the application of the ideas presented in lectures, and lecturers are fully aware of how well the material lectured on has been internalised by the class. In order to further support our non-major students in the Science Faculty, we have developed a series of pre-practical videos that students are able to view as many times as they think necessary before a laboratory session. Furthermore, in the first semester, we run a series of weekend and evening

> workshops in which students work collaboratively to solve physics problems with support from tutors and academic staff. This year we have also appointed a "Super Tutor" who organises additional tutorials with non-major students deemed to be struggling with their coursework.
>
> Computer Aided Laboratories with the assistance of tutors. A built-in software system gives students access to a suite of self-test multiple-choice questions covering the first year syllabus. This mode allows students to perform tasks fairly independently at their own pace.
>
> Increased use of AVU facilities, regular consultation session and display of latest scientific literature all around are some of the new modes of teaching and learning.

Student personal response systems ('clickers') have been introduced into classes in a number of HEIs, and these appear to have helped foster more interactive pedagogy.

It is evident from the responses that the adoption of structural changes such as the introduction of foundation/extended programmes, extra tutorials and more tutors are widespread amongst those Departments participating in the SER. However, with regards innovative teaching techniques it appears that, apart from one or two institutions, the adoption of these techniques occurs more at an individual level rather than as a result of 'buy-in' from the Department as a whole.

**Impact of innovation**

As we have seen, there is ample evidence of innovation. To guage impact of innovation, lecturers use pass rates, course evaluations and formal reviews to form impressions of the success of their teaching approaches. However, claims about what *actually works* really need to be supported by evidence-based research. It should be noted that no major changes were reported coming out of any course evaluation.[37]

This means that individual lecturers certainly develop a sense of whether or not to sustain an innovative practice with a particular class. However, without systematic, structured measurement over time ('hard' evidence), there is little possibility of Departments introducing *systemic* change informed by research. This point is clear in the following departmental response:

> Shortcomings are addressed and where possible adjustments made to the physics learning outcomes. Lecturer evaluation forms also provide data on various aspects of the course delivery including the pace, style of delivery, aspects of curriculum. However it is difficult to assess the impact of my teaching methods in one semester on the broader long term goals such as problem solving, practical skills, communication and report writing skills. These skills develop over the long term and can only be measured through intensive research.

There was little indication of such intensive research taking place. As one member of the Group concluded: "When we try things, we do not measure what's happening."

The initial impression obtained from an analysis of the responses is that Departments are indeed managing the challenges related to student preparedness. This is rather

[37] Described by one member of the group as "popularity polls of the professor".

surprising given the concerns voiced about the teaching and learning of undergraduate Physics across the South African public higher education landscape which gave rise to this review. Given the extent of under-preparedness of students entering HEIs it is difficult to believe that the structural changes introduced by Departments, together with a piecemeal adoption of innovative teaching techniques, would be sufficient to overcome these extensive latent deficiencies.

### *4.2.2 LIMITED INNOVATION IN STUDENT ASSESSMENT*

**Assessment and course goals**

It is a truism that assessment plays an important role in influencing the way students learn. Respondents to the Student Questionnaire found tests very helpful, with prompt (and detailed) feedback being of great value. Almost 90% were happy that the marking was fair (see Table 8, Appendix D).

Nonetheless, while there was general agreement between Departments on the attributes they wished students to acquire, in only one case was it clear that assessment was carefully aligned with the goals of the course:

> Individual lecturers take steps to ensure that our test and examination questions reflect the goals of the course (both those of the department and individual lecturer's specific goals which have been made clear to the students). Therefore any successful (passing) student has demonstrated a suitable achievement of these goals.

In general, it was not clear that the assessment was effective in ensuring that objectives and outcomes were aligned. This is therefore an area which needs much more attention.

**'Traditional' forms of assessment, and research**

'Traditional' forms of assessment, such as the following, were dominant in HEIs' descriptions of assessment.

> Continuous assessment mechanisms are in place. Evidence of students' learning is obtained mostly through a series of formative and summative tests, assignments, projects and lab work. Each of these carry their own weights with the largest proportion of the marks coming from a FISA (Final Integrated Summative Assessment) given at the end of the course.
>
> (a) Tutorial (b) homework; (c) tests; (d) practical work; (e) Exams
>
> Evidence of student learning is gathered in various ways – in-class activities, quizzes, assignments and tests. Within first year modules, in-class assessments and weekly assignments are used in a formative manner to inform the lecturer of students' progress, and to give prompt feedback to students on their learning.

Categorizing assessments as 'traditional' is not intended to attach pejorative connotations to the term 'traditional'. Assessment practices, as described in SERs, have an entirely respected place in the educational literature (and in criteria used by regulatory bodies). As in the case of innovative teaching approaches though, there were no indications that assessment outcomes were being researched in a way that might inform systemic change.

Rather, feedback to students was addressing the most immediate problems, e.g.

> We can tell from the performance in each question not only in what topics students are having difficulties, but also what specific skills to target for remediation.
>
> Assignments are marked and students get individual feedback as well as group feedback on common mistakes made and recommendations on how to improve their learning and skills.
>
> Frequent short tests allow one to pick-up problem areas at a very early stage, be it of a language, misconception or problem solving nature. This knowledge allows one to adjust your teaching methodology to apply more appropriate and explanatory communication techniques, use more application-type examples to improve problem solving skills or set tutorials that can address some of these short comings.

Again, while remediation with individual classes – which seems to be the watchword - is admirable, it does not lead to research-informed systemic change. One of the few indications that it might was expressed as follows:

> Student feedback unanimously supports the "whiteboard tutorials". Students report that these sessions allow them to seek clarity on the content and develop the problem solving skills required to apply the material. They have proved so successful, that we have formally requested that the Science Faculty assign senior physics courses two afternoons of the week (one for laboratory work and another for problem solving tutorial sessions).

On the other hand, a contrary view was expressed by one Department that appeared to argue that use of teaching and assessment for research purposes was somewhat futile:

> We feel that effective learning depends more on the student than the teaching method. At best, lecturers can excite students in the subject and motivate students to diligently work through assignments and examples.

This type of view exemplifies the hazards of externalizing the locus of control. If students are underprepared and lack work ethic, the unhelpful conclusion is that our role becomes one of teaching as usual – and as best we can – and hoping for the best.

## 4.3 THE STUDENT SURVEY

Student experiences in learning Physics represent the view of the learner. As explained above, Departments were required to identify students who would voluntarily complete the questionnaire. The Group noted that a drawback of the survey was that it might not be representative of the whole range of Physics ability of students in any Department. Nevertheless, student perceptions of Physics teaching and their corresponding methods of learning merits attention if the intention is to increase the number of Physics graduates.

This section summarizes the student view as it emerged from the online Student Questionnaire.

The conclusions that follow are best viewed against the students' 52% voluntary questionnaire return which reflects an obviously serious commitment on their part to contribute their own experiences and perceptions of learning Physics (see section 3.1.2.3). Furthermore, they did not simply 'tick the box': the great majority made use of the opportunity to explain their choices by adding thoughtful open-ended comments. In the section covering the competence of their lecturers, for example, 182 of the 218 respondents (83.5%) provided illustrations or reasons for their judgements.

### *4.3.1 Student perceptions on Teaching, Learning, Assessment, Resources and Academic support*

The detailed tables in Appendix D, Section 1, can be summarized as follows. A significant majority of students reported that:

- Lecturers, Demonstrators and Tutors are good at explaining things, and enthusiastic about what they are teaching.
- The Physics course is intellectually stimulating.
- The material covered by the physics curriculum is appropriate and valuable.
- Students personally made the most of learning opportunities in the form of lectures, practicals, tutorials and seminars.[38] Having been provided with preparation reading material, they felt well prepared for practicals.
- They valued the lecture programme, tutorials, demonstrations, and laboratory sessions backed up by tests and assignments.
- Physics courses run smoothly.
- They have made use of academic support, and are able to contact staff when needed; and they have been offered advice about learning Physics and future careers.
- They use a range of resources, but remain mostly reliant on their own prescribed textbook and notes. Nonetheless, as many as 41% have found other Physics textbooks that are easier to understand. Just over a third use textbooks in the library.[39]
- Assessment practices are fair; and they support the learning process in terms of prompt and detailed feedback.
- IT and library resources and services are adequate, and laboratories are well equipped and accessible.[40]

[38] However, not all institutions offer tutorials and seminars (see Table 5, Appendix D).

[39] One speculates that this is related to personal financial circumstances, but it might also be a matter of personal choice.

[40] However, across these issues, between 12% and 21 % disagreed. See second caveat below.

While these summarized judgements are based on student responses to both closed- and open-ended responses, it is of course always true that by the very nature of generalization, nuances are lost. Two caveats to the above are necessary.

First, student comments show that they did not find it easy to offer a single, generalized statement on the effectiveness and enthusiasm of *all* of their teachers. One third-year student expressed this succinctly: *"Some are [good at teaching], some aren't...".* Others, like this second-year student, offered qualified statements such as*: "Some lecturers I found to be extremely good at lecturing whilst others know their field but are not able to relate to where we, as students, are …"* Yet others, such as this third-year student, were less affirming of their demonstrators and tutors than they were of their lecturers: *"Not all demonstrators and tutors are good at explaining things. Some don't understand the experiments that they are demonstrating."* Nevertheless, students' overall judgment about the quality of teaching is based on unambiguous statements such as:

> They provide an opportunity to go an extra mile by sacrificing their afterhours time for us to grasp everything we can (honours student).

> The lecturers are well prepared and experts in their field. Effort is done to ensure that all learners know what is expected of them and to help them understand and succeed (third-year student).

The second caveat concerns the overall view that IT and library resources and services are adequate, and that laboratories are well equipped and accessible. This majority view masks inadequacies highlighted by students from historically disadvantaged institutions (HDIs):

> *Difficulty*: Physics is not difficult if you have interest in it. I didn't find it difficult. I only experienced that one in experiments. *Solution*: Provide us with good enough material to use in the lab (second-year student).

> *Difficulty*: The lack of practicals. *Solution*: Involving industries (honours student).

### *4.3.2 STUDENT VIEWS ON THEIR ACQUISITION OF KNOWLEDGE AND SKILLS IN THE PHYSICS COURSE*

Did students' learning benefit from the good teaching and the generally adequate teaching practices and resources they reported? The majority of students reported having gained "a lot" or "quite a bit" of knowledge and skills in all of the following key components of Physics investigated in the Student Questionnaire:

- Computational Skills
- Problem Solving Skills
- Physics Knowledge
- Research Methodology
- Project Planning Knowledge.

One would indeed expect Physics students to claim that they were learning Physics. Notwithstanding, the pattern of responses Table 3 (below) highlights interesting patterns of student response across successive years of study.

**Table 3: Percentage of students reporting to have gained "a lot" and "quite a bit" of knowledge and skills across the year groups**

| *Type of knowledge/ skill* | **First-year students** | **Second-year students** | **Third-year students** | **Honours students** | **Total: All students** |
|---|---|---|---|---|---|
| **Computational Skills** | 40.4 | 62.5 | 65.8 | 42.9 | 54.7 |
| **Problem Solving Skills** | 83 | 92.9 | 93.1 | 95.2 | 89 |
| **Physics Knowledge** | 90.4 | 91 | 95.5 | 100 | 92.6 |
| **Research Methodology** | 41.5 | 57.2 | 61.4 | 61.9 | 51.3 |
| **Project Planning Knowledge** | 41.5 | 57.2 | 61.4 | 61.9 | 51.3 |

**First,** if one reads horizontally across the rows, in the case of each of the forms of knowledge/ skills there is a consistent and progressive increase in the number of students reporting perceptions of mastery from each year of study to the next. There is but one exception, Computational Skills, in the case of which Honours students report less certainty than do the third-year students.

**Second**, as would be expected from the above, first-year students fall below the mean score for 'all students' in each case. With the exception of Physics knowledge, all second-year groups exceed the total mean; and without exception, so do all third-year groups.

While it needs to be borne in mind that we are looking at students' perceptions rather than a more 'objective' reality in the form of standardized test scores, it is certainly clear that students *grow in confidence* during the Physics course. But again, it has to be remembered that the present sample of respondents almost certainly represents the most able groups of Physics students.

Although limited in size and representivity, responses to the Student Questionnaire indicate that the students are generally satisfied with their experience in learning Physics. This corroborates the finding that, in general, the undergraduate climate is reported as good.

**Conclusion**

From the student perspective, the evidence obtained suggests that Physics courses, as presently offered, achieve their objectives in relation to the academically strong students. Given that the selection process is likely to be heavily skewed toward the more academically strong students, the results from the Student Questionnaire are probably less representative of the academically less well-prepared students. This is unfortunate as all evidence points towards the under-prepared students being in the majority.

## 4.4 Other issues relevant to improving undergraduate Physics

### *4.4.1 Physics departments and the training of Physics teachers*

**Involvement in the training of Physics teachers**

Since all Physics Departments appear to be well aware that, without their involvement, the standard of Physical Science teacher training will not improve, it is striking to find that there is very limited interaction between them and those departments involved in the training of teachers. Only one Department reported current involvement in the Physics component of teacher training programmes within its own university:

> We are actively involved in teacher training for existing teachers who wish to upgrade their qualifications (via the ACE professional development course), with a lecturer from Pietermaritzburg and one from Durban teaching the physics component.

Two other Departments reported *previous* involvement:

> In the past some lecturers assisted the Education faculty in teaching Physics courses.
>
> Before 2011, education students wishing to go and teach physical science routinely took our mainstream physics courses for at least two years. Some of the students even did all the physics we offer up to third year. Regrettably, this has now changed because the education faculty would like to have their students taught separately.

Other Departments noted, some in fairly terse terms, that they had no connection with the training of Physics teachers, e.g.:

> The department has no instructional offering for science teachers.

**Obstacles to involvement in the training of Physics teachers**

Though Departments appear to recognise the importance of providing academic support to these teachers as essential in improving the standard of the subject, they find it difficult to do so. To do this they need to address the following three obstacles:

**First**, there is lack of capacity. Teaching workloads within academics' *own* Departments are already extremely demanding.

**Second,** teaching outside of one's 'home' discipline raises tricky institutional issues. HEIs' auditing systems are based on the notion of 'full-time equivalent' (FTE) students serviced by lecturing staff. Allocating FTEs is complicated when staff teach across Departments, especially when an education faculty might be unwilling to cede some of its FTEs to another Department. (This issue might underlie the fact that in one of the above quotes, the "education faculty would like to have their students taught separately.") Any decision on the part of Physics Departments to become involved in teacher training could not be unilateral.

**Third**, if capacity can be created for staff to teach outside of the Physics Department, critical decisions have to be made about where energy could most productively be invested. Some Departments work with teachers at schools in their regions:

> We are NOT really involved with direct teacher training (only the Education department). On an individual basis some staff members closely interact with local high school teachers via the subject advisors.

However, it is worth noting that students' lack of preparedness for Physics entails more than just adequate physics teaching in schools, as the following quote illustrates:

> In 2011, we ran workshops on the teaching of mechanics. Obviously, we have a great concern about how physics and mathematics is being taught in high school, as it is evident that students are under prepared. However, we do not necessary believe that the only problem is that there is a lack of physics and mathematics specialists (although this is certainly a large part of the problem). In our opinion, the students are not trained to think critically or conceptually. They learn only basic problem solving techniques and rote memorisation, neither of which will lead to success at the tertiary level.

Notwithstanding capacity issues and other challenges, the Group was concerned about the very limited interaction of Physics Departments with teacher training. A parallel concern was that SERs reported hardly any formal attempts on the part of Departments to encourage their physics students to become teachers.

In this regard it was noted that at a national level South Africa lacks a programme run along the lines of the PhysTEC[41] project in the USA, whose aim is to improve and promote the education of future physics teachers. The PhysTEC project is jointly led by the American Physical Society and the American Association of Physics Teachers with the goal of increasing the number of good-quality physics teachers, promoting best practice ideas throughout the teacher training community and encouraging departments to become more involved in the training of physics teachers.

### *4.4.2 Reasonable recognition of the importance of physics education research*

**The extent of Physics education research**

As is the case with any discipline, Physics calls for the development of particular teaching approaches and strategies most appropriate for inculcation of the (unique) concepts that constitute the discipline. SERs indicated that staff are indeed encouraged to develop new teaching strategies and/or engage in Physics education research. However, the extent to which this actually happens is very uneven across HEIs.

[41]. www.phystec.org

**First**, as seen in section 4.2 above, there are few indications of *systematic* investigation into the impact of innovation in teaching and learning, other than those where Physics Education research is practiced.

> Three members of our department have specialised in Physics Education research, and they have administered several studies that aim to identify conceptual weaknesses and quantify class performances. The results of these studies have led to one PhD (with a further one in progress) and a number of papers at SAIP conferences.

**Second**, only four Departments indicated that their staff used sabbatical leave to undertake physics education research:

> Yes, since our department has a world-renowned Physics education group under the leadership of Profs Cedric Linder and Delia Marshall, we have staff that use their sabbaticals to engage in T&L research. The extended degree Physics (ECP) programme is evidence of this. Service courses, mainstream Physics and senior courses have adopted most of the techniques for incorporation in syllabi.
>
> Yes, there are several members of staff engaged in physics education research. Their sabbaticals are often spent engaged in physics education research. There is currently a plan to allow members of staff to have their teaching covered by colleagues for a term to allow them to develop teaching materials.
>
> The one lecturer with Physics Education received sabbatical leave in the course of her doctoral studies.

It is notable that the first two of these cases appear to involve departmental-led coordination; the fourth case appears to be a purely individual initiative.

**Obstacles to Physics education**

**First**, it is widely accepted across all disciplines that 'pure' disciplinary research carries higher status than does research into the education of that discipline. This is probably even truer in the case of the disciplines that enjoy higher status than many others – like Physics.

> As far as we know, members of staff have only used their sabbaticals for work in their research areas rather than physics education research. Some members of staff do take some time to revise their teaching notes during sabbaticals.

Despite the reality of underprepared students in higher education, it is approached in a rather uneven manner across the higher education landscape. 'Pure' disciplinary research generally carries a higher status than research into the teaching of that discipline. Like their disciplinary counterparts, Physics too is affected by the absence of clear directives from institutions regarding resourcing for Physics education.

**In addition** there are implications stemming from the ever-present fact that South African universities are themselves very uneven in respect of historical and present levels of resourcing. The following three quotes from HDIs provide a clear indication of why Physics education does not easily flourish:

> There is no functional sabbatical system at the institution.

> No sabbaticals.
>
> Current University policy dictates that sabbatical leave is only granted to staff with good recent research performance, and the University expects that such sabbatical leave is utilised for scientific rather than curriculum development purposes.

### 4.4.3 *Adequacy of Infrastructure*

For an experimentally-based discipline like Physics, adequate infrastructure is also essential for the teaching and learning of undergraduate Physics. Many of the participating Departments reported favourably regarding the budgetary allocations for the purchase of equipment or the maintenance thereof at their institutions. Whilst this may provide a picture of adequacy regarding infrastructure in Physics departments, it does not address the full picture. The question of adequacy of infrastructure across the higher education sector is rather uneven. Almost 20 years after the introduction of a democratic higher education environment, the previously advantaged institutions continue to benefit from a more robust infrastructure investment than their disadvantaged counterparts.

**Historically advantaged' HEIs**

In response to the question about the adequacy of the annual budget for purchasing and maintaining necessary capital equipment for teaching and learning, the 'historically advantaged' institutions typically replied with comments such as:

- "adequate";
- "more than adequate";
- "reasonable";
- "The Department receives just enough annual budget for purchasing and maintaining necessary equipment".

Some SERs also reported proactive measures to supplement budgets.

Furthermore, the views of Departments in 'historically advantaged' HEIs were mirrored by those of their students. In commenting on the state of their undergraduate laboratories and lecture venues, typical student comments included:

- "Lecturers have commented that they are 'not ideal, but suitable'."
- "Excellent. As stated above, all under graduate laboratories have been upgraded this year."

The following quote suggests that inadequate facilities, where these existed, were soon to be upgraded.

> 1st year labs: Laboratories are too small and crowded. Acoustics bad (groups can't necessarily hear instructor over the group next door), as well as too hot in summer. However, the executive has recently allocated sufficient funds to address these issues. 2nd and 3rd year labs: Facilities adequate.

**'Historically disadvantaged' HEIs**

The question of adequate infrastructure at historically disadvantaged institutions is one of concern. Physics as an experimentally-based discipline requires the support of the institution. This is however lacking as Physics Departments are expected to fund their own infrastructural needs. The citations from the SERs more than sufficiently demonstrate this.

> It is usually not enough since it is based on FTE's of the previous two years.
>
> No. Over the past few years the department had to fund the new ECP and Astrophysics course equipment costs from the normal operational CAPEX budget. The annual capital expenditure budget is too small for the needs of the department. There is no separate budget for maintenance of equipment and capital equipment acquisition and this poses a serious problem to effective teaching.
>
> Budgeting processes have not gone so well over the last four to five years. What is requested does not match what is given.
>
> The budget is not near what we should have liked to have. It is also not adequate for which we feel is essential to have. The result is that unnecessary duplication of practicals have to be done in order to enable all students to get their hands on the instruments.

The students too are concerned by this:

> Limited space (for lectures and labs) leads to overcrowding in certain cases.
>
> The laboratories are short of space, and much of the equipment is old or need servicing. The lecture venues are now adequate, with new lecture halls having been built by the university.

The adequacy of infrastructure in the teaching and learning of undergraduate Physics should be located in the larger context of this study. The crisis identified in the training of Physicists cannot be divorced from the infrastructural requirements the discipline demands. This is well demonstrated in the SERs and the Student Survey.

### *4.4.4 Ethics – a gap*

The only issue to arise from SERs affecting *content* is the position of *ethics* within the curriculum. Apart from issuing warnings about the consequences of plagiarism, only three institutions run courses on the topic and how it impacts on workplace and other practices.

### *4.4.5 Race and gender*

Race and gender are important considerations in higher education. In the case of Physics the responses to the SER demonstrate a gradual but still modest increase in the gender and racial mix of a discipline that was previously regarded as a male domain, and white dominated.

**Student profiles**

Detail on race and gender in SERs was too sparse to enable definitive statements on student profiles in Physics Departments. The main reason for the paucity of information is that, in many institutions, statistics on students are held in offices outside of departmental structures. Even if available, such statistics might reflect overall faculty profiles that are not disaggregated into departmental profiles.

Nevertheless, the available data suggests that while the student population has become mixed (to differing degrees) at previously 'white' institutions[42], there has been little shift in racial profile at most HDIs. In some, the student population remains 100% black.[43]

Available data on student gender profiles[44] at four universities indicates that males still predominate in 'mainstream' Physics, while females are reported to be better represented in the Physics 'service' courses.[45]

**Staff profiles**

Compared with student profiles, those of academics in Physics Departments were more fully represented in SERs. However, not all HEIs provided complete profiles, perhaps because the picture is complicated by tenured and contract appointments at different levels of seniority across various functions within Departments. It was not always clear that the profiles as reported referred only to academic staff. In a number of instances it appeared that administrative staff might have been grouped with academics.

The most complete HEI statement indicated that: "The physics staff is 34% African, 3% Coloured, 23% Indian, 40% White; 10% female & 90% male." Evidence of this representing a more widespread racial profile is provided by a follow-up survey[46]. Most Departments indeed appeared to have achieved a measure of racial balance, although this does not apply to all (see Appendix E, Table 15). Three institutions (one historically white, and two historically black) reflect no racial balance whatsoever: in the former, all Physics staff are white; and in the latter two, all are black. Given that there has been significant movement towards integration at the student level, this racial imbalance in the compostition of staff level is disturbing.

Available evidence in the SER suggests that women are seriously under-represented. In addition to the gender profile in the above quote ("10% female & 90% male"), one other Department stated that it had

> only one female academic, thus very low percentage. Support staff composed of females as administrators, and one female scientific officer out of 5, also low percentage.

A follow-up survey[47] shows that there have been even fewer advances in gender representation than in respect of racial transformation. In none the nine HEIs represented in Table 16 (Appendix E) do women comprise more than 20% of the staff complement. On average, in the nine HEIs, a mere 14% of Physics staff are women. With

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[42] 1st-year intake at UFS is 49% white, UP 38% white, Rhodes 38% white and Wits 19% white.

[43] UFH 100% African, UFS (Qwaqwa) 100% African, TUT 95% African.

[44] UFS 36% female, UP 24% female, Rhodes 30% female and Wits 41% female.

[45] Report on Regional Meeting, Western Cape, 22 November 2012.

[46] This survey was conducted by the Chair of the Group of Experts.

[47] Ibid.

females making up a significant proportion of the student population, it is indeed disturbing to find that they are so poorly represented at the staff level.

# 5. RECOMMENDATIONS: ENHANCING UNDERGRADUATE PHYSICS EDUCATION

To achieve the necessary five-fold increase in PhDs we need to produce large numbers of high quality graduates. While many aspects of this report seem to indicate that all is well within Physics undergraduate teaching and learning, the Group is concerned that there is little *quantitative* evidence supplied to support this view. The Group is firmly of the view that the true picture is not as promising as that painted by the more able Physics students (who certainly confirmed that undergraduate courses were meeting *their* learning needs). As indicated earlier in the report, it is difficult to conceive how Physics Departments are able to address the mathematical and scientific deficiencies in entering undergraduates within the three years of undergraduate education. While the pass rates reported by some departments may appear reasonable, without detailed knowledge of the content and the standard of the assessments it is difficult to ascertain whether Departments are in fact achieving their educational objective. If we are to achieve the five-fold increase in PhDs, reported pass rates can be considered acceptable only if the *quality* of the passes is equally good.

Substantive issues identified in this report are such that ***it is imperative that deep-seated changes regarding the length of the undergraduate programme and to the way it is taught and monitored be introduced***. Although possibly less far-reaching, other changes we recommend are no less compelling. If these changes are not made, nothing will change, and the crisis will persist.

In framing recommendations in respect of undergraduate Physics, the Group is acutely aware that the terrain is complex and diverse. For example:

- Physics education is also dependent on skills and attributes that students bring from other fields such as mathematical and language proficiency as well as their predispositions in respect of learning styles and problem-solving attributes.

- Physics courses themselves are bifurcated into 'mainstream' and 'service' courses. Even in the latter there might be significant differences between, for example, Physics for medical programmes and Physics for engineering.

- There are widespread differences and disparities across the contextual settings within which Physics courses are offered.

Nonetheless, the main issues identified in this review are sufficiently generic to enable us to make the following recommendations with conviction.

## Recommendation 1

### The SAIP should continue to coordinate the implementation of ways to enhance the undergraduate physics education.

The present report on teaching and learning in undergraduate Physics forms part of a broader formal SAIP initiative. Through Regional Meetings and other events, the present review has also strengthened or even opened up more informal discussions about teaching and learning – both within Physics Departments and across institutions. As an umbrella body, the SAIP could achieve much by continuing to coordinate formal processes and to serve as a reference point for the more informal initiatives.

## Recommendation 2

### A four-year Physics undergraduate programme should be adopted.

Accepting the reality that many students are underprepared when they enter the Physics programme, we believe that to enhance student success, we should adopt a four-year programme, as is the situation in many developed countries.

To some extent and in different forms - such as formally through foundation and extended programmes, or more informally through actual progression rates referred to above - a four-year programme is already becoming the norm for many Physics students. More important than actual rates of student progression, however is the nature of curriculum demand that arises from Physics, as a discipline. The conceptual coherence on which the discipline crucially depends presumes a hierarchy of abstraction and conceptual difficulty. "The more vertical the curriculum and the more crucial is conceptual coherence, the more sequence matters."[48] It follows that most undergraduate physics curricula are highly structured, with many prerequisite and co-requisite courses. Any student failing one undergraduate course inevitably ends up completing his/her degree in a haphazard fashion that is likely to be incommensurate with the conceptual coherence essential for a good understanding of the discipline . An extra year would allow for a slower pace of delivery and enable for greater scaffolding of material, while at the same time making it possible for a student to 'carry' a subject without compromising the structure of the curriculum.

In making this recommendation the Group of Experts is mindful of the fact that its recommendation of a four-year programme of study for undergraduate Physics has major implications for national policy governing degree structures. However, a number of obstacles that are commonly cited in opposition to a four-year structure might be not nearly as daunting as they might first appear. For example, a committee established by one Physics faculty has addressed two such 'obstacles' in its proposal to the CHE for a four-year BSc. First, the proposal includes a recommendation for accommodating those students who are capable of completing the Physics major in three years. Second, financial calculations show that the increase in costs incurred by a four-year programme is more modest than a straight three- to four-year percentage would indicate.

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[48] Muller, J. (2009) Forms of knowledge and curriculum coherence. *Journal of Education and Work.* 223 (3): 205–226. p. 216.

The Group thus firmly advocates a four-year undergraduate programme for Physics as being both optimal and feasible. Means of introducing a four-year degree should therefore be investigated, and any external recommendation for its introduction should be supported in the strongest possible terms.

## Recommendation 3

### We affirm and encourage the utilization and production of research into more effective ways of teaching under-prepared students.

Since traditional forms of teaching are unlikely to overcome the inherent deficiencies in students entering the undergraduate physics programme, new, innovative and effective teaching techniques need to be adopted. In doing so it is particularly important that the teaching of a discipline such as Physics is solidly grounded in research-based innovation.

**First**, Physics education has a long and proud history, and as such it is arguably one of the best developed fields of educational research. We therefore need to take maximum advantage of the vast amount of international science education research into innovative teaching techniques to guide us along this path. Social-interactive forms of teaching appear to be one of the most promising methods and this, when combined with a highly structured course design, has been shown to produced excellent results.[49] This is but one of the many examples of research findings that could be contextually appropriate in South Africa. While detailed guidance into the literature cannot be offered here, a very good point of entry into the literature would be the valuable collections of relevant research papers that are freely available from sources such as the Carl Wieman Science Education Initiative at the University of British Columbia.[50] Papers in this collection address many of the issues arising in the present report, and thus offer an excellent starting point for Physics lecturers wishing to incorporate research-led innovation into their undergraduate Physics teaching.

**Second,** Departments should be more strongly aware of the value of having active research groups in Physics education – or, at the very least, of having access to such groups in their region. The status of Physics education research relative to pure disciplinary research obviously cannot be legislated. However, if Physics teaching and learning is to be improved in a systematic way, Physics education research becomes an imperative. Apart from encouraging research into Physics education through the conventional channels such as sabbaticals, Departments could do much to promote this branch of Physics research by elevating its importance in staff recruitment practices.

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[49] See, for example: Freeman, S., Haak, D. and Wenderoth, M.P. Summer 2011. Increased Course Structure Improves Performance in Introductory Biology. *CBE—Life Sciences Education*, Vol. 10: 175–186.

Haak, D.C., HilleRisLambers, J., Pitre, E., and Freeman, S. 2011. Increased structure and active learning reduce the achievement gap in introductory Biology. *Science*, Vol. 332: 1213-1216.

[50] http://www.cwsei.ubc.ca/SEI_research/index.html

## Recommendation 4

### More appropriate and rigorous techniques of monitoring and evaluating Physics teaching should be employed.

This recommendation supports Recommendation 3 above. We note that in some cases a number of new and innovative methods of teaching have been adopted, but there appears to have been little systematic attempt to obtain reliable evidence of their effectiveness. There is therefore a need to improve the systems of monitoring and evaluating the methods of Physics teaching and assessment. The conventional evaluation techniques in use are of little value in this regard as they focus more on student 'satisfaction' or lecturer popularity than on conceptual learning.

We also strongly encourage the more extensive external peer review of Departments, which was found to be of great value in the past. Such reviews have the potential to improve both the quality of teaching and learning and the quality of Physics graduates. Furthermore, there is strong evidence that even experienced teachers can benefit from constructive peer coaching, which should also be encouraged.

## Recommendation 5

### Departments should guard against adjusting the standard of their degrees to accommodate students' lack of preparedness.

Lowering the standard of the qualification is neither in the interest of the students, nor the institution awarding the qualification. It is far preferable to set an appropriate standard and then manage the students up to the required level by effective methods of teaching and assessment. The peer review mechanism described above is but one method which would assist Departments benchmarking the quality of their courses against those in other institutions.

## Recommendation 6

### The issue of student work ethic needs to be better understood.

While all Departments raised the issue of unsatisfactory student work ethic, one must recognize that the issue is a complex one. Research shows that the problem is often one of a lack of understanding of how to learn among students. The origins of the poor work ethic therefore need to be thoroughly investigated and steps then taken to improve it. Specific interventions to address the problem do exist and should be tried (for example, the literature reports a 32% increase in performance in one case.)[51]

## Recommendation 7

### It is imperative that Physics Departments play a more active role in teacher training.

There is ample evidence to indicate that the deficiencies in incoming students are largely the consequence of ill-prepared physical science teachers. The SER data

[51] JST. 2012. Vol 41(6), 80-88.

however show that few Physics Departments are involved in the training of physical science teachers and this should be addressed. The voice, preferably in conjunction with the guiding hand, of Physics Departments is indispensable to improvement in the training of Physics schoolteachers. No agency other than the foremost experts in the discipline can play this role.

Few Physics Departments are actively involved in the support of science teachers in the field, and where capacity allows, this practice should be strongly encouraged.[52]

Within Departments, students should also be actively encouraged to become teachers.

To assist in the above, the SAIP should establish a project along the lines of PhysTEC, aimed at improving and promoting the education of physics teachers.

## Recommendation 8

### Support is needed for initiatives aimed at encouraging and supporting women in the Physics community.

Given that we could potentially significantly increase the number of students in physics by retaining more women, the existing activities of the WIPISA (Women in Physics in South Africa) forum should be strongly supported. Substantial research has been undertaken by the Committee on the Status of Women in Physics (CSWP) of the American Physical Society in the USA and the Institute of Physics in the UK into how this could be achieved. As an example, the Department of Physics and Astronomy of the University of New Mexico increased its enrolment of female graduate students from 7% to 25% in four years by a programme of extended outreach. The pool of students capable of studying Physics is too small to ignore women who could make a significant contribution to the discipline.

## Recommendation 9

### Physics communities of practice should be encouraged at the regional and national level.

The regional meetings undertaken during the review were found to be of great value. Participants emphasized, for example, the benefits of the opportunity to exchange information and to learn from each other's experiences.

We would encourage regional groupings of physicists to share ideas and encourage Physics education research (this could be done under the auspices of the present SAIP education specialist groups). This would be of particular importance in promoting the adoption and evaluation of new teaching methods in Departments.

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[52] Such endeavours might, however, be too piecemeal to have real impact. By contrast, what can be achieved at school level when associations equivalent to the SAIP take on an active role is well illustrated in: Lopez, R.E. and Schultz, T. September 2001. Two Revolutions in K – 8 Science Education. *Physics Today:* 44-49.

At a national level we would encourage the establishment of an IT Support Centre where innovative course material could be deposited and effective teaching methods described, thereby enabling best practices that are identified to be more rapidly embraced and shared throughout the physics community. Course material uploaded to such a support centre would also enable Departments to better benchmark their own standards and delivery of material.

## Recommendation 10

### The experiences of graduate students should be more closely tracked.

To determine that the needs of students are being met, Departments should make more effort to establish the goals of incoming students and keep track of graduates after they have left in order to see if these goals have been met. This would complement the monitoring and evaluation of teaching as well as assist the SAIP Physics 500 programme.[53]

## Recommendation 11

### Taking this undergraduate Physics review into account, the SAIP should formulate an action plan to move to the next stage.

Our final recommendation follows our first recommendation, namely that the SAIP should continue to coordinate the implementation of ways to enhance undergraduate physics education.

As the initiative thus rests with the SAIP, it would be inappropriate for the present review to make concrete recommendations regarding the *form* that an action plan should take. Nevertheless, it would not seem out of place for the present review to suggest possibilities, such as:

**Short term**

(a) Consideration could be given to a strategic planning conference attended by teams from all the South African Physics Departments, plus other observers/ participants such as national or provincial education representatives, the SAIP leadership and other relevant stakeholders interested in developing and enhancing student success in undergraduate Physics. The goal could be for each Department team to develop an action plan that they would take back to their Department and initiate steps to address the recommendations in this report. A possible template for such an event is appended (see Appendix F).

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[53] The Physics 500 Project is the beginning of an attempt by the SAIP to identify and track physicists in Industry. The purposes of the project are:

1. To identify industries in South Africa that employ physicists,
2. To identify physicists working in South Africa,
3. To use this information to promote physics,
4. To promote collaboration between the SAIP and industry.

http://physics500.saip.org.za/background.php (accessed 20 June 2013)

(b) The SAIP could consider setting up meetings between Education faculties/schools where the teacher training occurs and the Departments of Physics so the issue of increased involvement in the training can be discussed. The South African Education Deans' Forum could be a suitable entry point to such meetings.

**Long term**

(a) As a mechanism to support the all-important Recommendation 3 on the need for a flourishing network of Physics education research, the SAIP could include professional development workshops on implementing new pedagogies in the lecture room at each annual SAIP meeting.

(b) Noting that student performance in undergraduate Physics is also dependent on their schooling background in respect of learning styles, problem-solving ability, and proficiency in mathematics and language, the SAIP should seek ways of establishing lines of communication with appropriate national and regional bodies.

# APPENDICES

## APPENDIX A: GROUP OF EXPERTS

**The following members of the Group of Experts participated in the Workshop held at Leriba Lodge, Centurion, 29-31 January 2013:**

| **Name** | **Institution** |
|---|---|
| Professor Craig Comrie *(Convenor)* | University of Cape Town |
| Dr Joseph Asante | Tshwane University of Technology |
| Professor Makaiko Chithambo | Rhodes University |
| Dr Mmantsae Diale | University of Pretoria |
| Professor Harm Moraal | North West University |
| Professor David Wolfe | University of New Mexico (Emeritus) |

The work of the Group of Experts had the benefit of ongoing input and support offered by:

- Professor Ramon Lopez (University of Texas at Arlington), and
- Professor Carl Wieman (University of British Columbia).

**The work of the Group of Experts was supported by:**

| | |
|---|---|
| Professor Rehana Vally | Director: National Reviews, CHE |
| Professor Ken Harley | University of KwaZulu-Natal (Emeritus): *Report writer* |
| Barbara Morrow | Ngomso Research, Writing and Editing cc: *Scribe* |

# APPENDIX B: INITIAL LIST OF KEY ISSUES ARISING FROM THE SER (PER QUESTIONNAIRE ITEM)

**(i) Responsiveness of your department** (Questionnaire items 15-24)

- Major constraints to which departments have to respond are student underpreparedness, and their work ethic.
- Departments' responses to these constraints vary.
- There appears to be no data to indicate if the outcomes of strategies to deal with major constraints are successful.
- There is general agreement about the desirable characteristics of Physics graduates, and achieving these characteristics is the focus of undergraduate programmes.

**(ii) Level of preparation and the capabilities of students entering physics** (Questionnaire items 25-32)

- Knowledge of the level of preparedness of first year students is largely obtained at registration/admission, in class/tutorials and through diagnostic tests
- For weak students, special tutorials are arranged, or they are moved to a foundation or extended programme.

**(iii) Level of achievement upon completing physics courses** (Questionnaire items 33-40)

- Departments vary in the extent to which they adapt curriculum or teaching methods in response to student feedback.
- There is little evidence about whether or not such responses achieve their objective of improving the level of achievement.

**(iv) Are you serving every student who may benefit from studying physics?** (Questionnaire items 41 – 45)

- There is a need for more detailed data about the race and gender profiles within Physics departments.
- There is an increase in the number of black students attending historically white universities, but not the other way around.

**(v) Providing physics service courses to students:** (Questionnaire items 46-51)

- There seems to be little hard evidence about interactions between Physics departments and Physics teacher training. More evidence is needed.
- Departments seem to treat their service clients as they do their own.
- There seems to be too little collaboration between Physics and service departments on service course design and resultant accreditation.
- There appears to be little formal attempt to encourage Physics students to become teachers.

**(vi) Assessment** (Questionnaire items 94-99)

- Departments seem reasonably confident that they are assessing satisfactorily

- It appears, though, that fairly traditional methods of assessment are generally being used.

**(vii) Effectiveness of Curriculum to serve the students** (Questionnaire items 100-111)

- There is increased use of technology for delivery and course management (for example: Blackboard).
- Techniques for increasing social interaction to improve the quality of Physics teaching are used, but there is little hard evidence of their effectiveness.
- Regarding ethics: apart from warnings about plagiarism, only three institutions run courses on the topic.

**(viii) Innovation in teaching and learning: questions** (Questionnaire items 112-118)

- New modes of teaching are being explored, and this is supported by HEIs.
- Other than through course evaluations and pass rates, measures of the effectiveness of new modes of teaching are not well established
- Physics departments estimate the extent to which their courses or modules are current and up to date through measures including how recently published their textbooks are, and through comparisons with other HEIs
- There is evidence of innovations in laboratory-based work, but little or no indication that the effectiveness and/or relevance of such innovations is assessed.

**(ix) Staff establishment** (Questionnaire items 119-126)

- Most HEIs have some racial balance in their staff establishment; however, there was very little reporting on gender ratios.
- There is reasonable institutional recognition of the importance of physics education, but few institutions grant sabbaticals for research exclusively into Physics Education research (for example, into innovative teaching techniques)
- Most HEIs have training of some sort for tutors and assistants.

**(x) Infrastructure** (Questionnaire items 127-130)

- There seem to be reasonable Physics infrastructure and facilities at most HEIs
- Most budgets are adequate for the purchase and maintenance of capital equipment
- There are adequate funds to support new initiatives to revise classroom or laboratory courses, or create new ones.

**(xi) Is there a conducive climate to energize undergraduate Physics students?** (Questionnaire items 131-136)

- The general climate appears quite good
- There is little use of alumni to promote careers
- Given the general involvement of students in HEI governance, there is little evidence of this at Physics departmental level.

**(xii) Future development:** (Questionnaire items 137-141)

- Infrastructure and physical facilities appears adequate and not to be a constraint
- Question 140 produced nine suggestions about curriculum development.

# APPENDIX C: UNIVERSITIES WHICH SUBMITTED SER AND STUDENT SURVEY DATA

**Universities of Technology**

Durban University of Technology

Cape Peninsula University of Technology

Mangosuthu University of Technology

Tshwane University of Technology

**Universities**

North West University

University of Cape Town

University of Fort Hare

University of the Free State

University of KwaZulu Natal

University of Limpopo

University of Pretoria

Rhodes University

University of Stellenbosch

University of the Western Cape

University of the Witwatersrand

University of Zululand

**Comprehensive Universities**

Nelson Mandela Metropolitan University

University of Johannesburg

University of South Africa

Walter Sisulu University

# APPENDIX D: SELECTED TABLES CAPTURING STUDENT RESPONSE

## *SECTION 1: STUDENT PERCEPTIONS ON TEACHING, LEARNING, ASSESSMENT, RESOURCES & SUPPORT*

**Table 4: Student perceptions on the teaching of Physics** (# responses = 218; all figure are percentages)

| ***Aspect of teaching*** | **Strongly agree** | **Mostly agree** | **Neither agree nor disagree** | **Mostly disagree** | **Strongly disagree** |
|---|---|---|---|---|---|
| Lecturers, Demonstrators and Tutors are good at explaining things. | 37.2 | 49.5 | 10.6 | 1.8 | 0.9 |
| Staff are enthusiastic about what they are teaching. | 58.7 | 35.8 | 3.7 | 1.4 | 0.5 |
| The physics course is intellectually stimulating. | 54.1 | 35.3 | 7.3 | 2.3 | 0.9 |
| The material covered by the physics curriculum is appropriate and valuable. | 50.5 | 38.1 | 9.6 | 1.8 | |

**Table 5: Student attendance of learning experiences on offer** (# responses = 218; all figure are percentages)

| ***Type of learning opportunity*** | **Attended just a few** | **Did not attend any** | **Did not miss any** | **Missed a few** | **Missed many sessions (personal circumstances)** |
|---|---|---|---|---|---|
| Lectures | 0.9 | 0.9 (none were scheduled) | 53.2 | 43.1 | 1.8 |
| Practicals | | 0.5 (none were scheduled) | 95 | 2.8 | 1.8 |
| Tutorials | | 7.8 (none were scheduled)<br>1.4 (personal choice) | 67.4 | 22 | 0.9 |
| Seminars | 2.3 | 27.5 (none were scheduled)<br>4.6 (personal choice) | 39.4 | 17.4 | 8.7 |

**Table 6: Features of the course that students have found most helpful in learning Physics** (# responses = 218; all figure are percentages)

| *Activity* | **Very helpful** | **Fairly helpful** | **Helpful** | **Somewhat helpful** | **Least helpful** |
|---|---|---|---|---|---|
| Demonstrations in class | 48.2 | 28.9 | 11 | 4.6 | 7.3 |
| Laboratory sessions | 31.7 | 24.3 | 24.3 | 10.6 | 9.2 |
| Quizzes | 19.7 | 24.3 | 25.2 | 13.8 | 17.0 |
| Tests | 49.5 | 22.9 | 17.4 | 7.8 | 2.3 |
| Study group sessions | 22.5 | 29.8 | 20.2 | 11.0 | 16.5 |
| Tutorials | 53.2 | 25.2 | 10.6 | 6.0 | 5.0 |
| Worked examples in class | 61.9 | 23.4 | 8.7 | 4.1 | 1.8 |
| Homework assignments | 41.3 | 31.2 | 17.0 | 6.9 | 3.7 |
| Lectures | 48.6 | 29.8 | 13.3 | 4.1 | 4.1 |

**Table 7: Student use of physics textbooks** (# responses = 218; all figure are percentages)

| ***Type of textual source used for learning*** | **Strongly agree** | **Mostly agree** | **Neither agree nor disagree** | **Mostly disagree** | **Strongly disagree** |
|---|---|---|---|---|---|
| Use own prescribed physics text book extensively | 35.8 | 20.6 | 15.6 | 6.9 | 21.1 |
| Regularly use the prescribed physics text book in the library | 15.1 | 17.9 | 17 | 7.8 | 42.2 |
| Usually use other physics text books that are easier to understand | 20.6 | 20.6 | 21.6 | 7.8 | 29.4 |
| Rely extensively on notes made in class and handouts | 39.4 | 20.6 | 15.1 | 12.4 | 12.4 |

**Table 8: Students' experience of assessment practices** (# responses = 218; all figure are percentages)

| *Assessment practice* | **Strongly agree** | **Mostly agree** | **Neither agree nor disagree** | **Mostly disagree** | **Strongly disagree** |
|---|---|---|---|---|---|
| I usually receive detailed comments on my tests, tutorials, assignments and reports. | 30.7 | 33 | 13.8 | 13.8 | 8.7 |
| Feedback on my work has helped me clarify things I did not understand. | 49.1 | 23.5 | 11.9 | 6.0 | 5.5 |
| Feedback on my tests, tutorials, assignments and reports has been prompt. | 42.2 | 38.1 | 16.1 | 2.3 | 1.4 |
| The assessment questions and marking have been clear and fair. | 49.5 | 39.0 | 7.8 | 3.2 | 0.5 |

**Table 9: Student's perception of Academic Support** (# responses = 218; all figure are percentages)

| *Type of support* | **Strongly agree** | **Mostly agree** | **Neither agree nor disagree** | **Mostly disagree** | **Strongly disagree** |
|---|---|---|---|---|---|
| I have been able to contact staff when I needed to. | 30.3 | 33.9 | 14.2 | 10.6 | 11.0 |
| I have received sufficient advice about learning physics and future careers. | 32.1 | 32.6 | 19.7 | 10.6 | 5.0 |
| The physics courses are well organised and are running smoothly. | 44 | 40.4 | 11.0 | 1.8 | 2.8 |
| I made use of the academic support which the department provided to help me succeed with my studies in physics. | 30.3 | 33.9 | 14.2 | 10.6 | 11.0 |

**Table 10: Students' access to resources** (# responses = 218; all figure are percentages)

| *Type of resource* | **Strongly agree** | **Mostly agree** | **Neither agree nor disagree** | **Mostly disagree** | **Strongly disagree** |
|---|---|---|---|---|---|
| I have been able to access general IT resources when I needed to | 42.2 | 26.1 | 14.7 | 10.6 | 6.4 |
| The physics laboratories are well equipped and accessible when I need to. | 34.9 | 35.8 | 17.0 | 9.6 | 2.8 |
| The library resources and services are good enough for my needs for physics. | 37.2 | 28.0 | 22.5 | 7.3 | 5.0 |

## *Section 2: Student perceptions on knowledge and skills they have acquired*

**Table 11: Student perceptions on Computational Skills acquired** (# responses = 218; all figure are percentages)

| *Year of Study* | **A lot** | **Quite a bit** | **Some** | **A little** | **Not at all** |
|---|---|---|---|---|---|
| *Total : all years* | *24.3* | *30.3* | *19.7* | *11.5* | *14.2* |
| Year 1 | 18.1 | 22.3 | 21.3 | 16.0 | 22.3 |
| Year 2 | 23.2 | 39.3 | 16.6 | 8.9 | 8.9 |
| Year 3 | 29.5 | 36.4 | 15.9 | 6.8 | 11.4 |
| Honours | | 42.9 | 28.6 | 19.0 | 9.5 |

**Table 12: Student perceptions on Problem Solving Skills acquired** (# responses = 218; all figure are percentages)

| *Year of Study* | **A lot** | **Quite a bit** | **Some** | **A little** | **Not at all** |
|---|---|---|---|---|---|
| *Total : all years* | *64.2* | *24.8* | *9.2* | *0.9* | *0.9* |
| Year 1 | 54.3 | 28.7 | 12.8 | 2.1 | 2.1 |
| Year 2 | 76.8 | 16.1 | 7.1 | | |
| Year 3 | 63.6 | 29.5 | 6.8 | | |
| Honours | 71.4 | 23.8 | 4.8 | | |

**Table 13: Student perceptions on Physics knowledge acquired** (# responses = 218; all figure are percentages)

| **Year of Study** | **A lot** | **Quite a bit** | **Some** | **A little** | **Not at all** |
|---|---|---|---|---|---|
| *Total : all years* | *69.7* | *22.9* | *6.0* | *0.5* | *0.9* |
| Year 1 | 67.0 | 23.4 | 6.4 | 1.1 | 2.1 |
| Year 2 | 69.6 | 21.4 | 8.9 | | |
| Year 3 | 70.5 | 25.0 | 4.5 | | |
| Honours | 81.0 | 19.0 | | | |

**Table 14: Student perceptions on Research methodology knowledge acquired** (# responses = 218; all figure are percentages)

| ***Year of Study*** | **A lot** | **Quite a bit** | **Some** | **A little** | **Not at all** |
|---|---|---|---|---|---|
| *Total : all years* | *22.9* | *28.4* | *23.9* | *11.9* | *12.8* |
| Year 1 | 13.8 | 27.7 | 24.5 | 13.8 | 20.2 |
| Year 2 | 26.8 | 30.4 | 21.4 | 12.5 | 8.9 |
| Year 3 | 27.3 | 34.1 | 20.5 | 11.4 | 6.8 |
| Honours | 42.9 | 19 | 28.6 | 4.8 | 4.8 |

**Table 15: Student perceptions on Project Planning knowledge acquired** (# responses = 218; all figure are percentages)

| ***Year of Study*** | **A lot** | **Quite a bit** | **Some** | **A little** | **Not at all** |
|---|---|---|---|---|---|
| *Total : all years* | *22.9* | *28.4* | *23.9* | *11.9* | *12.8* |
| Year 1 | 13.8 | 27.7 | 24.5 | 13.8 | 20.2 |
| Year 2 | 26.8 | 30.4 | 21.4 | 12.5 | 8.9 |
| Year 3 | 27.3 | 34.1 | 20.5 | 11.4 | 6.8 |
| Honours | 42.9 | 19 | 28.6 | 4.8 | 4.8 |

# APPENDIX E: RACIAL AND GENDER PROFILES OF PHYSICS ACADEMICS

**Table 15: Racial profile of academics teaching Physics at HEIs**

<table>
<tr><th>Institution</th><th>African</th><th>Coloured</th><th>Indian</th><th>White</th></tr>
<tr><td>CPUT</td><td>37%</td><td>45%</td><td>5%</td><td>11%</td></tr>
<tr><td>DUT</td><td>30%</td><td>?</td><td>50%</td><td>?</td></tr>
<tr><td>NWU (Potch)</td><td></td><td></td><td></td><td>100%</td></tr>
<tr><td>Rhodes</td><td>33%</td><td></td><td></td><td>67%</td></tr>
<tr><td>TUT</td><td>50%</td><td></td><td>13%</td><td>37%</td></tr>
<tr><td>UCT</td><td></td><td>7%</td><td>7%</td><td>86%</td></tr>
<tr><td>UFH</td><td>100%</td><td></td><td></td><td></td></tr>
<tr><td>UJ</td><td>31%</td><td>4%</td><td>12%</td><td>53%</td></tr>
<tr><td>UKZN</td><td>34%</td><td>3%</td><td>23%</td><td>40%</td></tr>
<tr><td>UP</td><td colspan="3">44%</td><td>56%</td></tr>
<tr><td>UNISA</td><td colspan="3">70%</td><td>30%</td></tr>
<tr><td>SU</td><td colspan="3">31%</td><td>69%</td></tr>
<tr><td>Wits</td><td>19%</td><td></td><td>26%</td><td>55%</td></tr>
<tr><td>UZ</td><td>100%</td><td></td><td></td><td></td></tr>
<tr><td>WSU</td><td>62%</td><td></td><td>38%</td><td></td></tr>
</table>

**Table 15: Gender profile of academics teaching Physics at HEIs**

| Institution | Male | Female |
|---|---|---|
| DUT | 80% | 20% |
| Rhodes | 83% | 17% |
| UCT | 87% | 13% |
| UKZN | 90% | 10% |
| UP | 81% | 19% |
| UNISA | 80% | 20% |
| US | 94% | 6% |
| Wits | 89% | 11% |
| WSU | 87% | 13% |

# APPENDIX F: POSSIBLE TEMPLATE FOR STRATEGIC PLANNING CONFERENCE ON PHYSICS EDUCATION

*(This template was provided by Professor Ramon Lopez)*

**Goal**

Departments are to develop concrete strategic plans for addressing the recommendations of the findings from the self-study of physics departments.

**Structure**

The workshop will be organized along principles that have been successful in precollege science education reform [in USA]. In this model, the elements of reform are as follows:

1. Exemplary instructional materials and best practices (research-based)
2. The material infrastructure to support 1.
3. Ongoing professional development to support 1.
4. Assessment that is aligned with instruction
5. Departmental and Administrative support.

The workshop would begin with a report of the self study, then provide examples of possible pedagogical approaches that could address known issues. Teams would then have facilitated planning time to discuss what concrete steps they can take at their own institution. The remaining elements of reform would be addressed in a similar fashion, each incorporating findings from the report as appropriate. Student retention and program improvement would be addressed in 4. Beginning a dialogue around physics involvement in teacher preparation would be in 5. For each element, teams will develop concrete steps to take on the 3-month, 6-month, and one-year timescale. These plans will be shared among all of the teams.

**Possible agenda** (could be spread out over 4 days – depends on the details of each topic)

*Day 1*: Introductions, Overview, Greetings from CHE/SAIP

Review self-study findings: Examining the crucial weaknesses

Developing goals for your program

The case for active learning and examples

Interventions to improve success: Self-efficacy, Scaffolding math knowledge

Planning session 1 – Materials, practices, infrastructure

*Day 2*: Some features of institutional change 1. Professional Development

Planning session 2 – Professional development

Roundtable discussion: Developing shared resources

Assessment issue 1: Assessing students – When? Why? How?

Assessment issue 2: Recruiting and retaining students

Assessment issue 3: Feedback and evolving your program

Planning session 3 – Assessment

*Day 3*: Sharing status

Planning session 4 – Reviewing what we have done

Some features of institutional change 2. Cultural change

Teacher education – A role for physics departments?

Planning session 5 – Acting as change agents

Final sharing of plans, Adjourn to begin the real work.

## Addendum to Template for Strategic Planning Conference on Physics Education

The Group of Experts believes that a sizeable number of school-leavers are 'lost' to the tertiary system - and to Physics specifically - mainly because of financial reasons and lack of adequate communication. It therefore notes that a strategic planning conference of the type proposed above would best be preceded by a market analysis.

The question for such an analysis would be: *In view of critical shortage of maths and science teachers, are we drawing every worthy potential candidate?*

Answers to this question could be based on 'Matric' results in relation to university registration statistics. We need to know how many matriculants with adequate levels of knowledge and skills (as reflected in matriculation symbols) are available for tertiary Physics training, after all the other fields that attract them (engineering, health sciences, biology, etc.) have been taken into account. If it emerges that there is a sizeable pool of adequately qualified students that does *not* enter university, then the workshop would need to include consideration of strategies to attract adequately qualified students into Physics teacher training. On the other hand, if the available pool of potential students is already mostly utilized, the workshop could concentrate more exclusively and purposefully on strategies for more effective Physics teaching.