

A critical assessment of first year entering university science students' conceptual understanding

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Abstract

Meaningful conceptual understanding is a key requirement for the acquisition of applied knowledge for the navigation of sophisticated studies in science and engineering. It is a known fact that the academic migration of students from the school sector to institutions of higher learning is essentially accompanied by the existence of conceptual knowledge gaps in various content domains. In response to this difficulty and as a critical component of the First-Time Entering Students' Orientation programme, a diagnostic questionnaire was administered among 222 first year science and engineering students at the University of Johannesburg prior to the commencement of the academic programme in order to establish the nature and extent, if any, of their conceptual knowledge gaps. In terms of its design, the diagnostic questionnaire encapsulated items based on various conceptual knowledge areas pertaining to Grade 8 to 12 Physical Science learning domain. Analysis of students' responses exhibited the existence of conceptual gaps which may impede meaningful learning.

Introduction

According to the findings of the Report on the Review of Undergraduate Physics in South Africa by the Council of Higher Education (CHE) and the South African Institute of Physics (SAIP) [1], school leavers are inadequately prepared for Higher Education studies in physics. They cite lack of adequate mathematical skills (analytical, problem solving, manipulative, visualization and algebraic) and curriculum reform as major impediments in students learning and understanding physics at tertiary level. Curriculum reform entails the abolition of the differentiated HG/SG system in all the learning domains and the implementation of Mathematics and Mathematics Literacy for example as viable alternatives.

There are many signs of a "failed" South African school system, from local and international benchmarked tests. For example, the Trends in International Mathematics and Science Study (TIMSS) [2] test in mathematics and science proved to be too difficult for grade 8 learners to comprehend and was subsequently given to grade 9 learners as an ancillary. The performance by this cohort of students was equally dismal with South Africa (SA) featuring 41st out of 42 countries. In another report, the World Competitiveness Report (2012-2013), sanctioned by

the World Economic Forum [1,3], placed South African learners 143rd out of 144 competing countries and the latest report in 2014 revealed that South African learners as the last among the 148 countries.

In contrast, for students to be admitted for higher studies in physics such as honours and Bachelor of Technology (B. Tech.), a student needs to obtain a minimum of 50% for diploma and 60% for a degree course. According to the data provided by the diagnostic report on the 2013 Senior Certificate Examination (NCS) [4], of the total cohort that wrote the examination, only 25.6% were comprehensible for degree admission while 36.8% were intelligible for diploma related studies. The inspirations for students wanting to study physics at school level are dwindling as the following numbers testify: 205 364 in 2010, 180 585 in 2011, 179 194 in 2012 and 184 384 in 2013.

The impact of student under-preparedness among first-time-entering students at universities manifests itself in students taking much longer to finish a traditional B.Sc. degree in regulation time. Lecturers are faced with many challenges such as large class numbers and a student population of diverse cultures and ethnic backgrounds. Further compounding this issue they bring with them much reduced subject knowledge required for higher studies. The thrust of the lectures will be a deviation from traditional-type teaching approach to one that is more learner-centred, implying closer interaction with the students by providing more tutorials, remedial classes and a closer monitoring of at risk students. Universities in SA have addressed student under-preparedness by the introduction of foundation and extended programmes for students to improve their subject knowledge and give the students a second chance to complete their studies in an extended period of time. In the light of the above, it is imperative to discern the subject knowledge they bring with them to the universities which is the primary purpose of this report.

Methodology

A questionnaire in the form of a quiz which covered Physical Science from grades 8 to 12 was given to senior members of the Department of Applied Physics and Engineering Mathematics of the University of Johannesburg for comments and suggestions. A one page quiz was administered to first year entering university students (n = 222) in the fields of Engineering, Optometry, Food Technology and Biotechnology. The topics covered in the quiz ranged from general science in the General Education and Training (GET) phase to Physical Science in the Further Education and Training (FET) phase. To test the students'

scientific skills and abilities, a broad array of topics such as density, work, energy and electricity were assessed. The precondition of the questionnaire was that it had to conform to two criteria, namely the adherence to the school syllabus and to the manageability of the students. Besides the specific topics covered by the questionnaire, other additional aspects such as subject grades and whether the compulsory laboratory practical work as dictated by the curriculum was a normal occurrence at schools.

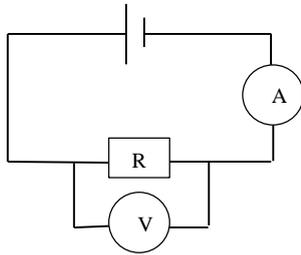
Data collection and discussion

During the orientation week, students were asked to complete the quiz without any prior notice or preparation whatsoever. The quiz of 30 minute duration consisted of 7 subject specific questions from grades 8 to 12. The students were asked to show all their calculations alongside the questions, and were only required to tick one option from the alternatives given. If the students were uncomfortable with a particular section, they were given alternate options such as “Never seen this question before” or “I cannot work it out”. These options gave us insight into the cognitive level of understanding of the sections done at school level. The use of the calculator was optional. A summary of the type of questions, excluding the options (for most questions) and the relevant syllabus coverage is given in Table 1 below.

Table 1: Type of questions

QUESTION	SYLLABUS IDENTIFICATION
1. A rectangular wooden block is 5 cm long, 3 cm high and 2.5 cm wide. The mass of the block is 26 g. Calculate the density of the wooden block.	Basic general science question from the grade 8 science syllabus.
2. “Frosted glass” is an example of A. Transparent material B. Translucent material C. Opaque material D. None of the above E. I cannot remember this one	A definition question from the grade 9 syllabus

3. Consider a closed circuit as shown below
 How will the voltmeter (V), ammeter (A) reading change if bulb of resistance R is burnt out during an experiment?



An electricity question from the grade 10 syllabus

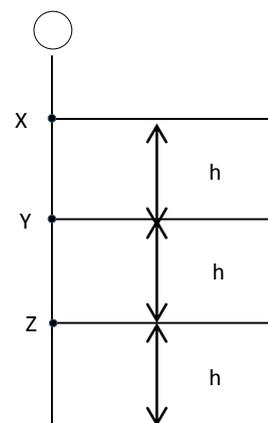
Options	Ammeter reading	Voltmeter reading
A	increases	Increases
B	Becomes 0	Becomes 0
C	Becomes 0	Does not change
D	Decreases	Becomes 0
E	Does not change	Decreases

4. A person stands on a bathroom scale which is placed inside a lift. When the lift is stationary, the reading on the scale is X newton's. What will be the reading on the scale if the lift is moving at constant velocity downwards?

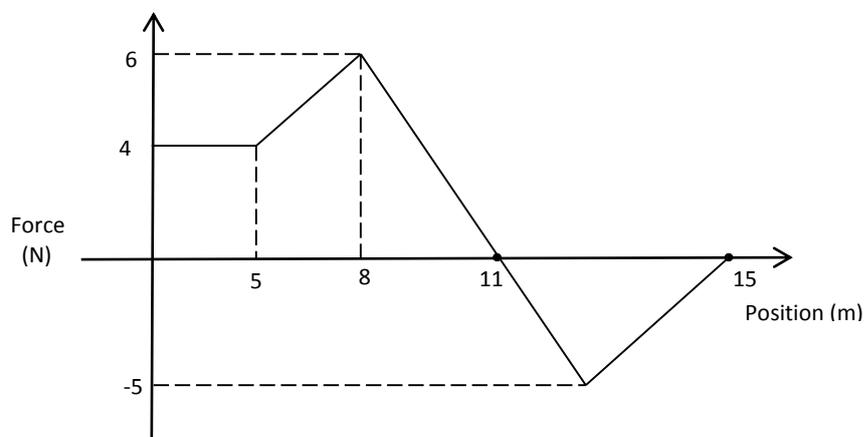
A grade 11 question on Mechanics

5. An object is in free fall. The picture below shows its motion. Find the ratio of the kinetic energy at point Z to the total mechanical energy of the object

A grade 11 question on Energy



6. A graph representing applied force versus position of an object is given below. Find the kinetic energy gained by the object as it travels a distance of 15 m.



A grade 12 question on Work and Energy

7. Lithium, beryllium and mercury have work functions of 3.68×10^{-19} J, 3.90×10^{-19} J and 4.5×10^{-19} J, respectively. Light with a wavelength of 400 nm is incident on each of these metals. Which one of these metals will exhibit photoelectric effect?

Grade 12 question on Photoelectric Effect

Cumulative results from the performance of students in the various fields of study is given in Table 2 below

Table 2: Summary of performance

QUESTION NUMBER	GRADE	CORRECT OPTIONS OPTED BY
1	8	35%
2	9	26%
3	10	15%
4	11	45%
5	11/12	21%
6	11/12	11%
7	11/12	16%

The performance by students in Question 1 which involved the calculation of volume is most appalling to say the least. It indicates that the students do not understand the basic concepts taught. The recall type question number 2 was not well answered which points towards the fact that students did not learn the basic laws, principles and definitions taught in the early

grades of science. Students appear not to have a firm foundation in the understanding of electrical circuits and this concurs with the moderators' report on the grade 12 Senior Certificate Examination in which the comment was that 'the electrical circuits was the worst answered of the whole examination paper' [4]. The most incorrect option for the question on electrical circuits was option E instead of option C. Of all the sections assessed, in question 4, a section on mechanics was a little better answered because of the insufficient time devoted to it in school. Question 5 which involves the determination of work done from a graphical representation has proved to be most challenging for students to solve. This points to the lack of sufficient examples done at school level to reinforce the concept: *Work done = Force x displacement*. A large percentage of students have performed equally badly in Question 6 which tested the principle of conservation of energy and this also suggests that students are not exposed to sufficient problems of a similar nature at school. In Question 7, students appear to have confused the concepts of work function of a metal and threshold frequency. Quite a number of students (16%) answered this question by providing the following option: "None of the above" or "I cannot work this problem out". This shows that students have a poor understanding of Photoelectric effect due to possibly shallow teaching that is taking place in many schools.

On the other hand if the performance of students in the quiz were to be narrowed down to those that obtained 80% or higher in the grade 12 Physical Science examination, the results are quite astounding, indicating the poor status of Science in South Africa. Of the cohort of 222 students that attempted this test, 12 students have obtained over 80%. In spite of the examination was written barely a month ago since writing this quiz, their subject knowledge leaves a lot to be anticipated with achievements as low as 18% for the top end of the students in Physical Science, which is a crisis of enormous proportion. A summary of the performance of the 12 top students is given in Table 3 below.

Table 3: Summary of the performance of the top students

QUESTION NUMBER	GRADE LEVEL OF THE QUESTION	CORRECT OPTIONS SELECTED (%)
1	8	55%
2	9	27%
3	10	27%
4	11	27%

5	11/12	36%
6	11/12	18%
7	11/12	18%

To get an insight to the extent at which laboratory practicals are done at schools, a survey coupled with the quiz was administered. The results are awful to say the least. The requirement by the Department of Education for each school to do at least 2 compulsory practicals is a ambitious dream as many schools are totally under resourced to carry out that mandate. Understanding of the fundamental principles in science through practical work is of paramount importance to the understanding of the theory [1]. The survey has revealed that only 42% of the students are actually doing some form of practical work at school while 50% of them are opting to learning the topics purely theoretically. 8% of the students claim to be doing some sort of practicals.

These results points to the scenario that students are struggling to come to terms with the FET syllabus. The lack of foundational competencies taught in the early grades coupled with shallow teaching that is taking place in the classroom could be one of the contributing factors for under-performance in the FET phase. In many instances teachers may be rushing through the syllabus in order for the students to write a common department paper. On the other hand teachers with the required level of subject speciality in both Chemistry and Physics can be questionable. The provision of over-abundance of resource materials could be counter-productive as this does not allow the students to think abstractly. The very predictable nature of the matric examination and the adjustment of the grade 12 examination marks leave much to be desired about its worthiness. With such a dismal performance it is inconceivable how these students will cope with studies in the exact sciences at tertiary institutions where abstract and logical thinking are essential.

Conclusion

The lack of adequate mathematical skills can be an impediment to the learning of physics at higher levels. Students appeared to have difficulties with most of the learning areas in physics covered in school. The presumption of assumed knowledge that is supposed to be in place should not be taken for granted. A baseline test needs to be put in place prior to any meaningful learning [5]. Students also appear to have forgotten the basic skills acquired from their early years of learning and it is these gaps that are compounding the situation. The

absence of any form of laboratory practicals in some schools is a cause for concern. The trend that each year fewer numbers of students are taking physical science as a subject in school is a serious problem for South Africa where technology innovation is a requirement for the 21st century. The idea of using the National Benchmark Test (NBT) as a criterion for admission at university is being debated in South Africa as there appear to be no correlation between the NSC examination and the results of the NBT tests.

References

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