**How much do first year physics students really understand? An entry-level test.**

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**Abstract:** The intake of first-year physics students in Higher Education Institutions has grown considerably over the last four years, and there has been even greater increase in student diversity. In order to academically support these students effectively, and to ensure the subject they take remains relevant, the academic preparedness of these students must be determined. For these reasons, the University of Johannesburg lecturers for first year physics introduced, at the beginning of the year in 2012, a physics skills test to determine the level of incoming students’ understanding of basicmechanics. This paper presents and discusses the main misconceptions that students have on the concepts assumed to be a prior knowledge as they enter their first year physics course. From this study some recommendations will be suggested.

1. Introduction

Pure BSc and engineering students at the University of Johannesburg (UJ) enroll for a standard calculus- based Physics course which serves as an introduction to their degree. Failure to obtaina satisfactory pass mark of 50% in a such course renders them ineligible to embark upon their degree of choice leading to the significant attrition experienced in science and engineering faculties at the university level. Globally, industry demands an increasing number of Science, Engineering and Technology (SET) graduates (Smaill, Godfrey, & Rowe, 2007). However, the number of secondary school students well prepared for studying SET at university level is shrinking in many countries (Smaill, Godfrey, & Rowe, 2007). In South Africa there is an increase in the number of students pursuing studies in SET but there is relatively low first semester completion rates by students entering first year university studies. At UJ the first semester of the first year of study is one of the major factors for early drop-out from university, since a pass in this semester is the pre-requisite to enroll for second semester. In order to support these students effectively, and to ensure the course remains relevant, their academic preparedness must be determined. However, recent changes in South African (SA) school curriculum and how national examinations are conducted have made this difficult (Yeld, 2009,Jansen& Phakati, 2011). For example, in the past all students who chose to study mathematics and physical science in their secondary schooling were required to study standard grade (SG) or higher grade (HG). In the recent years, only one grade paper is written by all students, and it makes it difficult to determine their preparedness.

Physics 1(Introductory physics), mechanics, is part of the compulsory module for all incoming first year science and engineering students at UJ. For a fundamental introductory mechanics course at university level the topics to be studied include areas such as kinematics, dynamics, Newton’s Law of motion, work and energy, impulse and momentum, and rotational motion. Four hundred and twenty six (426) and three hundred and six (306) students enrolled in the three year and four year program, respectively. To enroll for a three year program the student must have obtained a minimum of 60% overall mark and for a four year program the student needs a minimum of 50% overall mark from the National Senior Certificate (NSC) results. Since the inception of the National Curriculum Statement (NCS) and introduction of NSC in high school in 2006 the number of students achieving university entrance scores has increased. A total of 496090 candidates sat for the matriculation exams in 2011, 70% of whom passed. Of those who wrote exams, 24.3% qualified for university study (DoE, 2011). The University of Johannesburg experienced more students registering for science and engineering courses in the last three year see table 1.

More than half of students registering for module 1 in semester 1 at UJ do not enroll for module 2 in semester 2, due to various personal reasons. It has been observed that some of those enrolled in physics for a four year program do not pass the first module of physics or fail one or more other modules. Other reasons that some students from a three year program fail to qualify to write examinations and some of those that manage to write don’t do well in them. As means of establishing the readiness of the students in respective physics program, a physics skills (diagnostic) test was given to first year students and administered in February 2012 (see Table 1 below).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Subject Codes | 2008 | 2009 | 2010 | 2011 | 2012 |
| PHY1(3year) | 332 | 461 | 374 | 483 | 426 |
| PHY1A1E(4Year) | 128 | 207 | 169 | 454 | 306 |
| Total | 460 | 668 | 543 | 937 | 732 |

Table 1: A table showing the total number of students enrolled for physics year-one.

The lecturers were greatly surprised by the extent to which students’ misconceptions in mechanics were revealed. The development of the physics skill test was informed by previous years’ first class and semester tests results obtained by students in physics three year and four year programs, respectively.

**Physics Skills Test (PST)**

A physics skills test has been designed for students entering the mechanics module in the first semester of introductory physics first year. The test consists of a 20 multiple choice questions related to basic understanding of the principles of Mechanics, Waves and Thermodynamics (which the student should have learned in the high school physical science). Each question tests knowledge that the student is expected to be able to produce without special preparation, and that should be well understood by him/her. For example the student might be asked to execute a vector sum or evaluate the magnitude and direction of the vector.

1. Methodology

The physics skills test were given to two different groups of 2012 first year physics students: one being part of a three year degree program and the other being drawn from a four year degree program. The test consisted of 20 multiple choice questions and was administered for a one hour period at the beginning of the first quarter. The test was administered to a total of 423 participants of physics 1 students UJ from 732 registered students. The participants were divided according to the programmes they enrolled into and it must be mentioned that not all the students wrote the test. The three year (n= 157) passed their grade 12 physical science with 60% or above, while the four year group (n = 266) only passed their grade 12 physical science with marks in the range of 50-60%. The test was written by students at their convenience over a period of a week in the beginning of the second week of their semester on the Electronic Learning Media (Edulink) platform. Each student attempting the questions needed to login and finish test in an hour.

1. Results and Discussion

**The Physics Skills Test, Initial Analysis**

The physics skills test has been given to two different groups of 2012 first year physics, that is, three year degree and four year degree programmes. The total number of students completed the 20 question test are 157 and 266, respectively. Test statistics reveals that the time allocated to the test appeared to be sufficient, as a significant number of students finished the test with adequate time to spare. Other students however made full use of the allocated hour working on their answers. Mark histograms are provided in Figures 1 below.



Figure 1: Mark the histogram(s) for 2012 Physics Skills Test

Figure 1 confirms that for most questions the correct response rate is low, showing a lack of understanding of the pre-conceived physical science concepts. Both groups (3-year and 4-year programs) did not show much difference in terms of their averages which were calculated to be 32% and 29% for a 3-year and 4-year program, respectively.

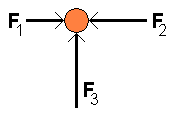
This indicates that certain simple pre-knowledge skills, which the test assumes students can execute, will often be incorrectly answered. To enable us to interpret these results, some of the questions were selected for in-depth analysis to provide understanding to some of the misconceptions the students had.

**A close look at some of vector questions**

**Analysis of selected PST questions**

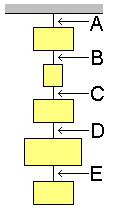
In question 8 shown below, the results were of considerable concern, as they revealed significant misunderstandings of a fundamental and elementary concept. Only 6% of the students gave option (E), the correct answer. By contrast, 42% thought the answer was option (C). Clearly the misconception outlined above is well-established and widespread. This indicates that a significant (based on which statistical package?) percentage of students from both groups does not have a conceptual understanding of the definition of a vector and vector addition. They cannot make use of the Cartesian plane (axes) to determine the magnitude and directions of vectors. Of course, they would have an idea of definition of a vector quantity and knowledge of resultant vector.

Q8: In the diagram below you are looking at a mass on a frictionless surface from above. Three forces act on the mass as illustrated in the diagram. F3 > F2 and F2 > F1. The magnitude of the resultant force acting on the mass will be:



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| A | B | C | D | E | F | G | H |
| **F3 - F2 - F1** | **F3 + F1 - F2** | **F3 + F2 - F1** | **F3** | Slightly bigger than F3 | **F1 + F2 + F3** | I do not know the answer because I do not understand the Physics in this question. | I do not know the answer because I do not understand some of the words used in this question |

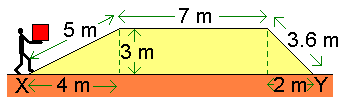
Q.11: Five boxes are tied together by identical strings and tied to a ceiling by another string identical to the others (see diagram). The large box in the diagram is also heavier than the others, and the smallest box is the lightest. Which string is most likely to break?



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| A | B | C | D | E | F | G | H |
| where the top box is tied to the ceiling | just above the small box | just below the small box | just above the big box | just below the big box | All strings A-E are equally likely to break | I do not know the answer because I do not understand the Physics in this question | I do not know the answer because I do not understand some of the words used in this question |

In question 11, only 46% of the students gave option (A), the correct answer. 24% thought the answer was option (D). This indicates that a significant percentage of students do not have a conceptual understanding of tension and weight. The misunderstanding of weight is revealed by the answer (D) showing that this group thinks that the bigger the box means more weight applied on the string just above it. About 10% of students thought the answer was (C), their reasoning could be that they thought the sum of the masses of the boxes below the small box will give more weight and more stress on the string just below the small box.

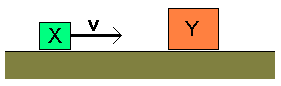
Q13: A person carrying a box with a weight W (W = mg) is walking up the hill from point X, along the flat top, and then down to Y. What is the work done by the person for the entire trip from X to Y?



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| A | B | C | D | E | F | G | H |
| zero | 3W Joules | 5W Joules | 6W Joules | 13W Joules | All strings 15.6W Joules | I do not know the answer because I do not understand the Physics in this question | I do not know the answer because I do not understand some of the words used in this question |

In question 13 above a disappointing 31% of students gave the correct option (A) as the answer. 17% of students thought (E) is the correct answer, presumably as in the figure above students just added all x-axis values to get a displacement (13 m). A small percentage (8%) gave option (D), apparently adding the 4 m and 2 m in the x-direction to get the displacement. It seems as if they realized that at the end of the journey the displacement in the y-direction is zero. Clearly, students know the definition of work-done (W= Fcosθ.s) but do not have a clear understanding of the calculation of displacement in relation to the above given diagram. Only 31% managed to realize that displacement is zero. Literature shows that students still hold misunderstanding about vector addition even after they have been taught vector addition (Wutchana & Emarat, 2011).

Q15: This question relates to the same physical setup as in the previous question. The small box X moves with speed v and kinetic energy E0 on a smooth horizontal surface towards the heavier stationary box Y. After the boxes rebound, X moves to the left with a kinetic energy EX and Y moves to the right with a kinetic energy EY. Some heat is generated during the collision. What is always true about the relationship between E0, EX and EY?



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| A | B | C | D | E | F | G | H |
| E0 > EX + EY | E0 = EX + EY | E0 = EY - EX | E0 = EX - EY | E0 < EY - EX | E0 < EX - EY | I do not know the answer because I do not understand the Physics in this question. | I do not know the answer because I do not understand some of the words used in this question |

While a simple knowledge of conservation of energy may have helped 27% of students to the correct answer (A) for the questions illustrated below, 52% of students opted for (C) or (D) and arrived at quite nonsensical results through blindly relying on the definition of conservation energy without considering the loss of energy through some heat generated during the collision. They could have noticed a loss of energy but lacked the skill to determine the correct answer.

1. Conclusion and Recommendations

The physics skills (diagnostic) term test was disappointing but also enlightening. It appears to indicate that most of the class either had not understood or had forgotten much of the basic physics they were supposed to have covered in high school. The recent NCS introduction of NSC for high-school qualification may have led teachers to adopt a more learner-centred teaching style which, in turn, encouraged students to adopt a more fragmented approach to their learning.

More remarkably, success rates for many of the individual questions corresponded very closely between the two samples. The test shows that the NSC results may not be used to place students to a particular group, since students produced similar and, at times, identical statistics. The physics skills (diagnostic) test acted as a “wake-up call” and led to behavioural changes on the part of many students and to some modification of the course teaching style. A question-by-question analysis has proven valuable, with the most significant feature to emerge from the analysis being the basic (pre-tertiary) level at which the misconceptions occurred.

This study recommends that some intervention be made early in the year and the amount of time allocated to understanding of basic mechanics concepts be increased because the mechanics concepts are the core in introductory first year physics. We hope that the recommendations would enhance pass rates and throughput and hence more students would as a result progress to the second semester of their first year.

1. Acknowledgements

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