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 lecturers in the first year physics introduced in 2012 a physics skills test at the beginning of their course to determine the level of understanding of basics mechanics acquired by the incoming students. 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 put forward as to the effective teaching approach to be employed for maximum throughput at the end of the first year semester 1.

1. Introduction

Pure BSc and engineering students at University of Johannesburg (UJ) undertake a standard calculus-based Physics course as an introduction to their degree major. Failure to attain a satisfactory pass mark of 50% in such course renders them ineligible to embark upon the course for their major and may contribute 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. However, the number of secondary school students well prepared for studying SET at university level is shrinking in many countries. In South Africa there is an increase in the number of students pursuing studies in SET and 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 enrol for second semester. In order to support these students effectively, and to ensure the course remains relevant, the academic preparedness of these students must be determined. However, recent changes in South African (SA) school curriculum and how national examinations are conducted have made this difficult. 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. 426 and 306 students enrolled in the three year and four year program respectively. To enrol for a three year program the student must have obtained a minimum of 60% overall mark and for a four year program student needs a minimum of 50% overall mark from National Senior Certificate (NSC) result.

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 the matriculation exams in 2011, 70% of whom passed. Of those who wrote exams, 24.3% qualified for university study [1]. 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 enrol for module 2 in semester 2, due to various reasons for individual students. It has been observed that some of them, enrolled in physics four year program do not pass the first module of physics or even fail one or more modules from other enrolled subjects. The other reason is that some students from a three year program fail to qualify to write exam and some of those that manage to write an exam don't do well in it.

Subject Codes	2008	2009	2010	2011	2012
PHY1A01(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.

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. The lecturers were greatly surprised by the extent of the students' misconceptions in mechanics that was 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 questions related to a basic understanding of the principles of Mechanics, waves and thermodynamics (which the student should have learned in their 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.

2. Methodology

The physics skills test has been given to two different groups of 2012 first year physics, one being part of three year degree class and the other drawn from the four year degree programmes. The test consists of 20 questions, is designed for multiple choice answers, and is given in an hour period at the beginning of the first quarter. The test was administered to a total of 423 physics 1 students from the UJ.

The sample was divided according the enrolled programmes and students attempted the test, where the three year (n=157) group passed their grade 12 physical science with 60% or above, while the four year program (n=266) sample only passed their grade 12 physical science with marks in the range 50%-60%. The test was done 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.

3. Results and discussion

The Physics Skills Test, Initial Analysis

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.

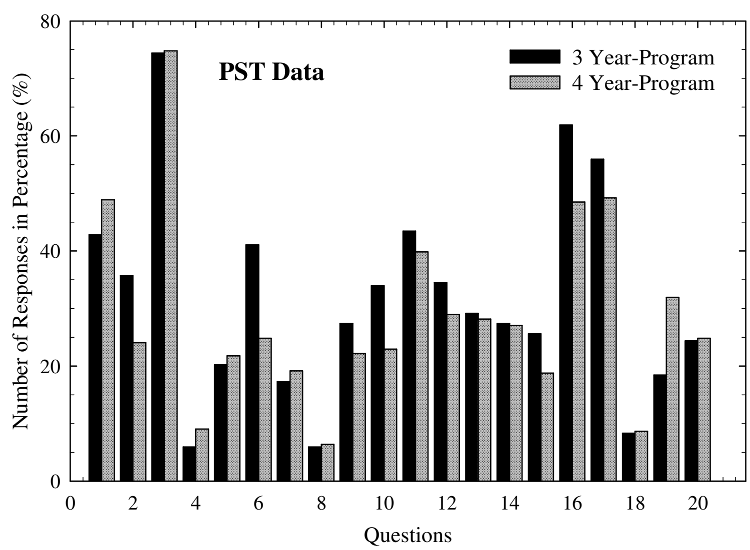


Figure 1: A histogram showing the percentage of correct students' responses in respective questions given in Physics Skills Test 2012.

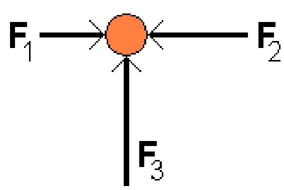
Figure 1 confirms that for most questions the correct response rate is low, showing a lack of understanding of the pre-conceived physical science concepts. Both groups (3-year and 4-year program) groups did not show much difference in terms of their averages which were calculated to be 32% and 29% for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

Analysis of PST selected questions

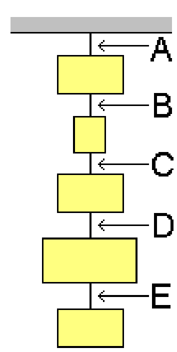
In the question 8 shown below, the results were of considerable concern, as they revealed significant misunderstandings of a fundamental and elementary concept. Only 6% of the students gave option (E), the correct answer. By contrast 42% thought the answer was option (C). Clearly the misconception outlined above is well-established and widespread. This indicates that a significant percentage of students do 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. $F_3 > F_2$ and $F_2 > F_1$. The magnitude of the resultant force acting on the mass will be:



A	B	C	D	E	F	G	H
$F_3 - F_2 - F_1$	$F_3 + F_1 - F_2$	$F_3 + F_2 - F_1$	F_3	Slightly bigger than F_3	$F_1 + F_2 + F_3$	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

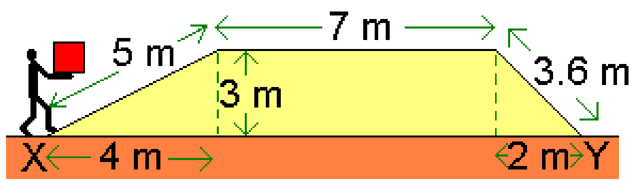
Q.11: Five boxes are tied together by identical strings and tied to a ceiling by another string identical to the others (see diagram). The large box in the diagram is also heavier than the others, and the smallest box is the lightest. Which string is most likely to break?



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 think 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.

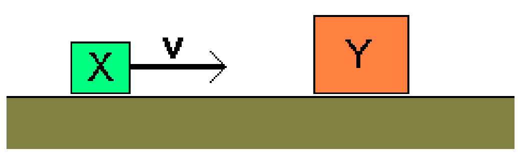
Q13: A person carrying a box with a weight W ($W = mg$) is walking up the hill from point X, along the flat top, and then down to Y. What is the work done by the person for the entire trip from X to Y?



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.

Q15: The small box X moves with speed v and kinetic energy E_0 on a smooth horizontal surface towards the heavier stationary box Y. After the boxes rebound, X moves to the left with a kinetic energy E_X and Y moves to the right with a kinetic energy E_Y. Some heat is generated during the collision. What is always true about the relationship between E_0, E_X and E_Y?



A	B	C	D	E	F	G	H
$E_0 > E_X + E_Y$	$E_0 = E_X + E_Y$	$E_0 = E_Y - E_X$	$E_0 = E_X - E_Y$	$E_0 < E_Y - E_X$	$E_0 < E_X - E_Y$	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.

4. Conclusion

The physics skills (diagnostic) 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.

The results across the two groups were very similar. 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 behavioral 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 will enhance pass rates and throughput and hence more students will as a result progress to the second semester of their first year.

References

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