University students’ performance in different types of exam questions informs on their problem solving skills as well as studying ability

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Abstract. An evaluation of students’ performance in different questions in an exam at the end of a first year Physics major course, at the University of the Witwatersrand, in terms of the different skills required to answer each question, leads to insight into their level of problem solving and studying skills. Student performance, in a Physics I major test and a Physics II major test, both at the end of the first semester, is also evaluated. The students in the evaluations found questions that were new and required more intuitive, or lateral and logical type thinking, the most difficult to answer. The students, surprisingly, also found some questions that required the memorization of material only, also difficult to answer. Problems that only required a routine operation, or plugging into an equation, seen many times before, were perceived by the students as the easiest type of question to answer. These results also inform on the type of learning and studying the students have been acclimatised to due to the type of instruction received prior to entering university.

1. Introduction

Problem solving is a central component of learning and doing physics. Physicists need to use problem solving techniques in order to advance the current knowledge of physics. The strategies applied by trained physicists are however usually quite different from those of physics university students. Trained physicists use qualitative techniques [1], such as diagrams and physical principles to solve problems. Students lack these skills; they have difficulty connecting different aspects of a problem and in using the information available to solve the problems. A problem solver transforms into an expert problem solver through experience, that is, he transforms into a physics problem solver who has the ability to intuitively know what principles to apply and how to apply them [3].

Any instructor therefore attempts to encourage students to ‘think like a physicist’ [1]. This usually means that students are encouraged to draw diagrams and to apply the principles, such as Newton’s second law, or conservation of energy, to different problems where appropriate. Specific problem solving instruction, however, has been demonstrated to actually make physical concepts less understandable to students [2]. This is because when students see a specific method for solving a problem they seem to see steps that follow one after the other rather than the broader principles that need to be applied to this type of problem. It is therefore only when students are faced with a problem of the same type but yet different from the one for which they have seen the solution that they begin to realize that it is principles that have to be applied and not a specific set of steps that is always the same for a certain set of problems.

Thus, if a physics instructor has any hope of teaching students how to think like a physicist it is imperative that new problems that require the different skills, needed to eventually 'think like a physicist', are set before them. The research presented here looks at how students perform when faced with such problems in exam and test conditions. Problems set for a test or exam requires different skills, namely:

1. Book-work knowledge: This includes definitions, laws and principles that are specifically taught to the students.
2. Intuitive thinking: This is the ability to make logical connections that are not immediately obvious, between different given information.
3. Routine operation skills: This includes the mathematical techniques needed to manipulate equations in order to solve for the desired physical quantity. It also includes the insertion of number values into equations.
4. New problem thinking: Here in the absence of a solution that could have been memorized, the problem solver has to create his own solution, using his knowledge of the physical principles involved in the specific problem, and his knowledge of how these principles should be applied.

Trained physicists, who work at the frontier of physics, also need to have bookwork knowledge, need to use intuitive thinking, and need to be able to use routine operations, even though these may be a lot more complex than those encountered by students.

2. Method

Questions in the Physics I major 2012 November exam at the University of the Witwatersrand were evaluated in terms of skills listed above, namely: Bookwork knowledge (BW), intuitive thinking (INT), routine operation skills (RO) and new problem thinking (NP). Thereafter students' performance in the different questions was analysed using a spreadsheet previously designed by Clerk, Naidoo and Shrivastava [4]. The same process was repeated with the Physics I major class test in May 2013 and with the second Physics II major Classical Mechanics class test.

In addition, a questionnaire, shown in Figure 1, was designed and given to the Physics I major students after completion of the May class test.

Physics Test questionnaire

Date: 24 May 2013 Student Number: ………………………………

Test: Physics I Major class test 2 written on 20 May 2013
Look through the test and decide which three questions were the most difficult and place them in order below:

Most difficult question: …………….
Second most difficult question: ………………
Third most difficult question: ……………

Now consider the question you found to be the most difficult and select one of the following:
I found the question difficult because: (tick one of the following)
A: I did not study the relevant sections of the course properly so I had no idea what to do
B: I studied the relevant sections of the course but I did not know how to start solving the problem
C: I knew what principles to apply in order to solve the problem but did not quite know how to use them in this case.
D: I managed to solve the second part of the question but not the first because there was something about the application involved in solving the problem that I did not understand
E: Other, write down your own explanation below:
………………………………………………………………………………………………………

Figure 1: Questionnaire given to Physics I major students after their second class test in 2013. The questionnaire offered the students an opportunity to declare which of the four questions they found the most difficult and to give an explanation using the four different suggested options and/or one open-ended last option.

The open-ended option was designed to allow students to provide more insight into their difficulties when faced with the test questions.

3. Results

The results obtained from the analysis of the 2012 November exam appears in Table 1. The first two rows in the table show the question number and parts in each question. The third row shows marks assigned to each question. The total number of marks in the paper was 100 and the number of students who wrote was 182. The average mark obtained by the students for each question part is shown in row 3 as a percentage (%). Rows 4 to 8 show the different skills required by each question as determined by the lecturer. A rating of 0 for some skill means that the question does not require that skill, and a rating of 5 means that the question only requires that specific skill. For example, question 1 has a rating of 2 out of 5 for bookwork (BW) knowledge, 2 out of 5 for routine operation (RO) skill and the degree of novelty of the problem is rated as 1 out of 5.

Student performance for questions 9a and b is extremely good. These questions were rated as being routine operation questions, thus showing that these are the types of questions that students find to be the easiest. The question with the lowest student performance is question 3, where the average performance is only 17%, and this question is rated highly, 4 out of 5, for new problem type thinking skills. Surprisingly, questions that require only bookwork knowledge, questions 5a, 14a and 14b, also show a relatively low performance average, namely, 38%, 51% and 31%, respectively. This suggests that the students have difficulty with this type of question as well but not as much as with the problems that require a lot of new problem thinking. The question that requires the greatest degree of intuitive (INT) thinking is question 13b in which students also performed badly, achieving an average performance of 18%. This question was rated relatively high by the lecturer, with a 2, for new problem (NP) thinking skills required, so this may have contributed to the students' low performance. Question 10 also has a rating of 2 for NP thinking skills and a rating of 1 for INT thinking skills but the average performance for that question is higher at 52%, which demonstrates that the degree of intuitive thinking required by the question plays an important role in students' performance.

Table 1: Student performance in the November 2012 Physics I major exam.

Number		1	2		3	4	5	6	7		8		9				10	11		12		13		14	
Part			a	b					a	b	a	b	a	b	c	d		a	b	a	b	a	b	a	b
Out of:		7	6	3	6	7	10	7	4	3	5	2	1	2	2	2	6	5	5	4	4	3	2	2	2
Average %		79	75	44	17	82	85	69	51	58	38	53	91	93	77	50	52	38	42	74	39	67	18	51	31
Type:	BW	2	2	2	1	0	2	2	1	2	5	2	0	0	0	0	1	5	1	0	0	0	0	5	5
	INT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0
	RO	2	3	3	0	3	3	3	1	2	0	0	5	5	5	5	1	0	1	3	2	2	1	0	0
	NP	1	0	0	4	2	0	0	3	1	0	3	0	0	0	0	2	0	3	2	3	3	2	0	0

The analysis of the results from the second Physics I major class test, which was written in May 2013, is shown in Table 2. This test was written by 323 students and the total number of marks for the test was 50. The table has been populated in a similar manner as Table 1 with an additional row included that defines one more type of thinking, namely: complexity. Complexity, here, is referring to the complexity of the mathematical manipulations required to derive a final answer. The numbers assigned for complexity show that all the questions were of about the same complexity except for question 3. The total rating for the other types of questions, BW, INT, RO and NP, is still 5, but the rating given to complexity (CO) is in addition to that.

Table 2 shows that students performed the best in question 3, with an average mark of 61%, so complexity did not seem to present much difficulty for them. This question was rated by the lecturer to have some degree of routine operation skill. From Table 1, we have already found that the students find this type of skill requirement in a problem the easiest to deal with. The NP rating for this question is zero. The questions showing the least average performance are 2b, 1b and 1a which have a significant element of novelty with a new problem (NP) rating of 3. Therefore the NP thinking skill seems to be the one that leads to the lowest average performance from the students.

Table 2: Student performance in the second Physics I major class test written in May 2013.

Number		1		2		3	4
Part		a	b	a	b		
Out of:		8	8	4	4	12	14
Average %		32	28	55	19	61	44
Type:	BW	1	1	1	1	1	1
	INT	1	1	2	1	1	2
	RO	0	0	0	0	2	0
	NP	3	3	2	3	1	2
	CO	1	1	1	1	2	1

The third test to be analysed, in the same manner as the Physics I major November 2012 exam and the Physics I major May 2013 class test, was the second Classical Mechanics test given to Physics II major students. The test comprised of 44 marks and 46 students wrote it. The results of the analysis are shown in Table 3 below.

Table 3: Physics II major student performance in the Classical Mechanics May 2013 class test.

Number		1				2		
Part		ai	aii	b	c	ai	aii	b
Out of:		2	2	3	15	7	12	3
Average %		40	50	67	22	30	20	33
Type:	BW	5	2	5	4	2	3	5
	INT	0	3	0	0	3	2	0
	RO	0	0	0	0	0	0	0
	NP	0	0	0	1	0	0	0
	CO	0	0	0	3	0	2	1

From Table 3, we see that at second year level, the complexity in questions seems to play a role in the students' performance on that question, which was not easily visible at first year level. Questions 1ai, aii and b are rated with zero complexity (CO), whilst question 2b is rated as having low complexity. Question 2b was actually a first year level question so it was rated with 1 for CO. Questions 2aii and 1c have the highest complexity and the students performed the worst in those two questions. It is however also worth noting that question 1c was the only question to require a level of new problem type thinking and question 2aii required some intuitive thinking as well as having a relatively high complexity rating, namely 2. So NP thinking skills and INT thinking also play a role in the student performance.

Table 4: Percentage of Physics I major students choosing a category describing the reason for difficulty encountered with the questions in the May 2013 class test.

Category	**Percentage**
A: I did not study the relevant sections of the course properly so I had no idea what to do.	6.6
B: I studied the relevant sections of the course but I did not know how to start solving the problem.	34
C: I knew what principles to apply in order to solve the problem but did not quite know how to use them in this case.	44.3
D: I managed to solve the second part of the question but not the first because there was something about the application involved in solving the problem that I did not understand.	5.7
E: Other	9.4

The results from the questionnaire are summarized below. There were four questions in the test and 111 students chose to complete the questionnaire about the test. The number of students choosing each option in the questionnaire was added up and divided by the number of students who completed the questionnaire in order to obtain percentages for each available option. The percentage of students who thought that question 4 was the most difficult question was 51%. In addition 35% of the students indicated question 1 was the most difficult question, 37% responded that question 1 was the second most difficult question and 36% suggested that question 2 was the second most difficult question. So question 4 was thought by these students to be the most difficult, with question 1 being the second most difficult. This is a little surprising as the students performed better in question 4 than in question 1, as seen from Table 2.

The reasons students chose for finding a question difficult are shown in Table 4. By far the most popular category was C: I knew what principles to apply in order to solve the problem but did not quite know how to use them in this case.

Table 5 shows the categories that emerged from the open ended option E in the questionnaire. The different categories appear in the left column and an example of the type of response given appears in the right column.

Table 5: Categories emerging from the open-ended option in the questionnaire, with examples of student responses.

Category	**Student response example**
E1: I knew what principles to apply but did not study or practice this section well enough	*"I didn't practice enough for this section so I struggled to apply the theory of statics."*
E2: I knew what principles to apply but I did not have enough time.	*"It is because I had not enough time to answer the question."*
E3: There was not enough information in the data sheet	"*I am not sure if the data sheet had enough data."*
E4: I knew what to do but got stuck somewhere whilst solving	*"I knew what to apply and the problem was I got 2gl instead of 3gl and I couldn't manage to get 3gl and I didn't understand where 3gl came from."*
E5: There was something about the question I missed	*"I knew what I had to do, I applied the principles but there was a trick in the degrees that I didn't see. That led to me failing to answer the question."*
E6: I did not understand the wording of the question	*"I did not understand the statement of the question."*

The category attracting the most responses was E4: I knew what to do but got stuck somewhere whilst solving.

4. Discussion and Conclusion

The analysis of the Physics I major November exam 2012 and the Physics I major May class test summarized in Tables 1 and 2, show that students perform the worst on questions that require new problem type of thinking and best in problems that mainly require the routine operation type skill. The complexity required in the solution of the problem does not seem to play a role at first year level but does at the second year level, as indicated in the results appearing in Table 3.

The different open ended categories, E1 to E6, as shown on Table 5, are very interesting, the most popular was E4: *I knew what to do but got stuck somewhere whilst solving, with four responses reflecting this idea*. Since even trained physicists get stuck now and then we cannot use it to reflect on the degree of expertise of the students. But all the other categories are significant and reflect the problems encountered by students who have not learnt the concepts and principles they needed to learn in order to become expert enough to answer problems that are novel, namely they recognise they needed to practice the application of the principles more often (E1). The lack of expertise or practice may also lead to the students being slow in the application of the principles to the problem at hand and so run out of time (E2). Another problem is that they may expect the data sheet to supply all the equations they may need (E3) whilst they are actually supposed to memorize a few simple things or be able to derive them, again showing that the student failed to reach the expert level of skill required, and may still want physics to be a routine operation exercise. Other symptoms of lack of expert level skill is not understanding the question (E6) or missing something when reading it (E5).

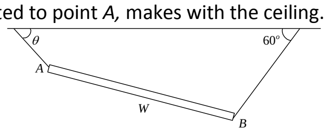
Other results obtained from the questionnaire are the main reasons for finding a question difficult and therefore underperforming in that particular question. As seen from Table 4, 44% of the students chose category C: I knew what principles to apply in order to solve the problem but did not quite know how to use them in this case, as their reason for finding a question difficult. This shows that the vast majority of the students knew which principles were to be used in solving the problem but not exactly how to apply them. The natural question to then ask is why? Why did they have this difficulty? Now let us look at the question in May 2013 class test that they found the most difficult, namely question 4, which is shown below:

A uniform rod of weight *W* hangs from the ceiling via two ropes connected to each end, as shown in the figure below. The rope connected to point *B* makes an angle of 60° with the ceiling. The rod makes an angle of 30° with the horizontal direction.

(a) Show that the tension in the rope at *B* is given by

$$T_B = \frac{\sqrt{3}}{4}W$$

(b) Find the angle θ that the rope, connected to point *A*, makes with the ceiling.



Note: $\sin 30^o = \cos 60^o = \frac{1}{2}$ and $\cos 30^o = \sin 60^o = \frac{\sqrt{3}}{2}$

This question is a standard first year statics problem, but what made it so difficult for the students? The students had seen a similar problem with a rod and strings at both ends in a tutorial problem but in that particular tutorial problem the rod had been horizontal. In the test question above, the rod is not horizontal. The students had however seen a problem from a previous test where the bar had not been horizontal but there was a hinge instead of a string at one end. The two diagrams used in the problems students had seen appear in Figure 2. So the combination of the non-horizontal rod with the two strings was enough to make this particular problem a novel problem to the students. Consequently many of them were not able to apply the required principles. This shows that many students (51%) had not reached the expert level of skill required to deal with a standard but novel question. These students had learnt solutions to the problems as a set of steps to follow and not as principles that can be applied to different problems.

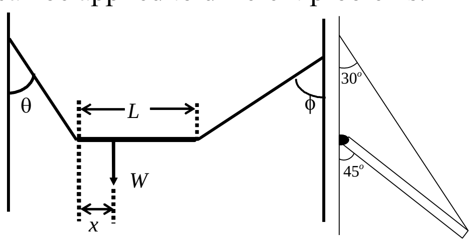


Figure 2: Diagrams used in the problems students had seen prior to the test.

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