Why is physics hard? Unpacking students' perceptions of physics

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Abstract. It has been well established that there are many challenges associated with physics teaching and learning. This pilot study attempted to identify the perceptions of first-year students studying physics at Rhodes University in 2017. Academics in the Department were interviewed, a questionnaire was created and a survey was conducted with first-year students. Emotional issues were identified as the largest contributing factor to students' perceptions of physics. A high correlation between study skills and students' understanding and problem-solving abilities was observed. Under-preparedness was recognised as an important issue that needs further investigation.

1. Introduction

In many ways, teaching physics poses a unique set of challenges. It is a subject that is perceived (and perhaps rightly so) as being difficult [1]. Teaching physics at university emphasises concepts, understanding and sound reasoning. In addition there is a requirement to develop strong analytical and mathematical skills in students. To address students' difficulties with physics, there is a need to have a greater understanding of the specific factors contributing towards their challenges. This study is an attempt to identify and understand these issues.

This project was a pilot study that attempted to interrogate the views of students studying physics at tertiary level and to identify their challenges. The focus of this study was the first-year physics class at Rhodes University in 2017. Interviews with physics lecturers were conducted in order to establish their insights and perspectives as to why they felt students struggled with physics. A focus group study was conducted with the second and third-year classes in order to obtain their retrospective perspective of the challenges that they experienced. Based on the interviews and focus groups, a framework of issues was established (see section 2) and a corresponding survey was conducted on the first-year class.

2. The framework

Based on the interviews with academics, focus group responses, past Rhodes University physics surveys (including the Colorado Learning Attitudes about Science Survey, CLASS, [2]), and results from existing literature, a number of factors were identified that potentially contribute to students' difficulties, shown in Figure 1. The various factors were categorised into three domains, namely *subject*, *cognitive* and *affective*. In addition various aspects of *study skills* were included to assess whether or not they played a role in student difficulties. The subject domain considers the challenges relating to mastering the discipline of physics. Informally, one can think of the remaining three categories as representing the students' *head* (the cognitive domain), *heart* (the affective domain) and *hands* (study skills). This categorisation is similar in nature to the problem-solving sub-skills identified by [3]. Each of the factors identified are discussed below with reference to the points raised in the interviews with the academics and in the focus groups with the second and third years. It was initially hypothesised that all domains would emerge as equally important and of equal concern.

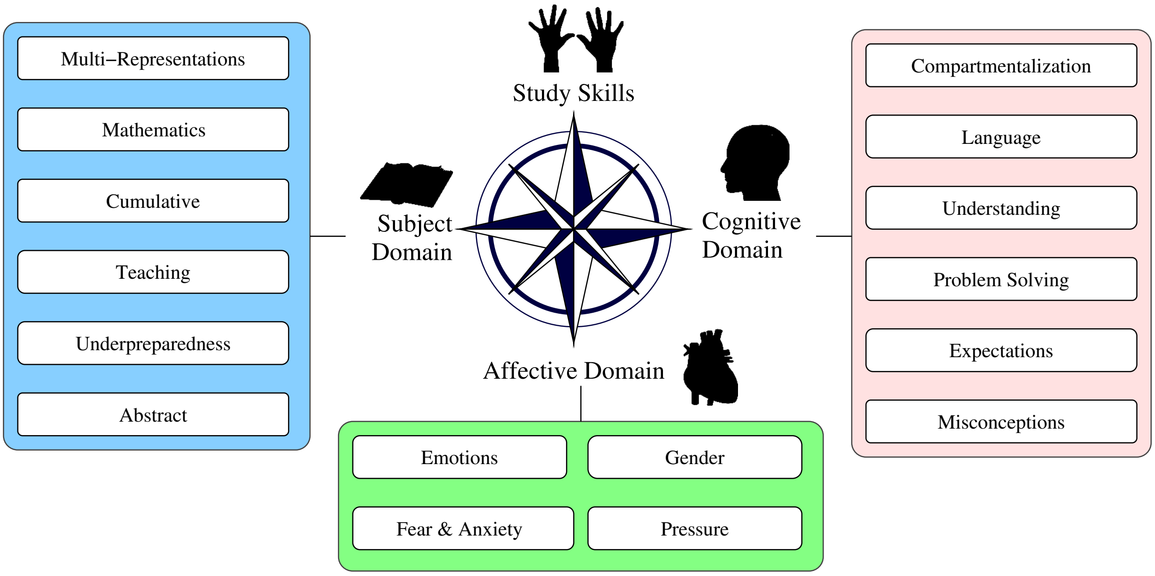

Figure 1. Factors contributing towards student difficulties with physics, grouped into various domains.

2.1. The subject domain

Multi-representations The academics recognised that a potential area of difficulty in physics is due that the fact that competence in many different representations is required. Some of the most commonly used representations are: pictures, diagrams, graphs and algebraic equations, for example. There have been several studies relating to different aspects of multi-representation (see, for instance, [4; 5]) which also point to the issue of multi-representation being a potential source of difficulty to students.

Mathematics All the interviewed academics complained about the poor mathematical skills of students. One of the issues that was identified was that students struggled to solve for a variable in complicated equations. Furthermore, they felt that students do not understand fundamental mathematical concepts such as functions. Trigonometric functions such as $\sin(x)$ and $\cos(x)$ are understood by many students as simply being "*buttons on their calculators*", without understanding what they really mean. There was also a perception that students lack confidence in their mathematical abilities.

Lecturers understand that students have usually just learned the mathematics and do not understand why they are doing it or what the applications of the mathematics in physics are. A study about the connections that students perceive between mathematics and physics supports this [6]. The academics expressed the opinion that this stems from under-preparedness and the dense curriculum that needs to be covered. In focus groups there was discussion of having a specific mathematics course for physics or a number of lectures where the mathematics required for the physics course is covered before the course begins.

The second- and third-year students emphasised that they find it hard to connect mathematics to the real world and that even though they know how to do the mathematics, they struggle to do the physics. They struggle to see the link between the mathematical concepts and formulas underlying physics. As the mathematics becomes more abstract, more effort is required to understand the physics and students often end up memorising formula but not knowing where or how to apply them.

Cumulative Both academics and students in the focus groups touched on the cumulative nature of physics and how it is important try to see the big picture. The students said that they sometimes "*lose the physics*" in the mathematics of a course or problem, and mentioned that time constraints on the courses make them more challenging.

Teaching Both students in the focus groups and the academics interviewed agreed that the quality of teaching affects how hard the subject is perceived to be. Factors related to the teaching of physics that were brought up in the focus groups were the variable pace of the lectures and the different approaches taken by different lectures with regard to assignments. The role played by teaching is acknowledged by Arons [7].

Underpreparedness The majority of lecturers commented that students are underprepared for university. A lecturer stated that, "*Students find it hard because they're not prepared enough. Physics at university is a level up from school and students often have an unwillingness to stretch themselves.*" These sentiments echo those of Venezia and Jaeger who commented that many students "*enter college without the basic content knowledge, skills, or habits of mind they need to succeed*" [8]. Within a South African context, the poor schooling system has been identified as the significant contributor towards the lack of preparedness for higher education [9].

Abstraction The academics identified two aspects of abstraction that could be contributing factors to the difficulties of physics. These were the abstract nature of some physics topics and the level of abstraction required between the real physical world and the mathematical description of it. Some students in the focus groups observed that it is difficult to "*see the purpose*" of some topics and to see where they "*fit in to the real world*".

2.2. The cognitive domain

Many of the factors in this domain fall into what has become known as 'the hidden curriculum' [10]. These are the elements of learning that are often not explicitly taught but which lecturers expect students to be able to perform. The importance of taking these factors into account has been increasingly recognised [11].

Compartmentalization Lecturers mentioned that students tend to compartmentalise their knowledge. They get 'locked into notation', "*they think variables are stuck and they cannot interchange symbols.*" Most lecturers commented that "*physics becomes easier when you look for the big picture instead of keeping it compartmentalised.*"

Language Lecturers pointed out that students do not have the ability to read with understanding. The lecturers recognised that the textbooks use 'big words', which is problematic for many of the students who are not first-language English speakers. In the focus groups students said that the lecturers sometime used words they did not understand.

Most of the students that raised this point did not speak English as their first language. After lectures, these students felt comfortable to approach the lecturer with questions.

Understanding Both the second- and third-year students mentioned the importance of understanding the concepts in physics rather than simply rote learning formulae and laws; they said, "*Our schools teach us to memorise and regurgitate facts, so it's a sharp transition when you get to varsity and you're expected to actually think.*". They also highlighted time constraints as an issue. They felt that they did not have enough time for concepts to sink in.

Problem Solving This was a concern raised by the academics, although the second- and third-year students did not refer to problem solving as a difficulty in the focus groups. The academics felt that students tend to learn procedures to follow, rather than genuinely solving problems. It is also a factor that has been given a significant amount of attention in the literature (see, for instance, [3]).

Expectations The academics interviewed recognised that students have expectations about what studying physics will be like. These expectations can either be based on the more 'exciting' physics that they read about in the media, or on what they have already experienced at school. They recognised that for some students the university environment might be radically different to what they are accustomed to. It has been found that students' expectations "*can play a powerful role in what they get out of introductory college physics*" [12].

Misconceptions Both second- and third-year students mentioned that the concepts learnt often seem "*counter-intuitive and infrequent in daily life.*" After marking student assignments, one tutor commented, "*These people must live in such a confusing world!*", alluding to the way that students construct their personal knowledge of the real world from experience even though that is in conflict with the way that world is described by physics.

2.3. The affective domain

Emotions Lecturers mentioned that if students "*do not have the right kind of support, physics can be lonely.*" The third-year students commented that they start to lose motivation when they spend more than a of couple hours on a single problem.

Gender Some of the second- and third-year students mentioned pressures due to gender stereotyping from their peers as a factor, saying that "*boys make fun of girls*". Another student commented that "*We [the girls] often found the boys' 'uncaring' state frustrating and insensitive.*".

Fear & Anxiety Lecturers understand that students have concerns entering physics at university. They felt that students fear failure and that they fear bad marks more than not understanding.
Students at all levels are worried about failing physics. A second-year student stated that he was worried about failing something he enjoyed. A concern raised by the third-year class is that they are worried that when they finish a course they might not remember everything. This could be because they have realised the importance of the cumulative nature of physics.

Pressure Academics acknowledged that "*sometimes the reasons are not academic*", that there might be issues at home or that students may not have enough money for living expenses.

2.4. Study skills

The students identified summarising courses and refining these summaries as a study skill that works. Other study skills that work were doing a number of different problems, watching other people do examples and spaced repetition. Study methods that did not work were rote learning, or, as described by a student: "*learning how to solve problems off by heart instead of from first principles*", and looking at tutorial solutions before attempting the tutorial were not succesful study methods. Most of the interviewed students said that they watch online videos to better understand the course work. However they do spend a while searching for what the students identified as a "*good*" video.

2.5. Method

These factors which were derived from the interviews with the lecturers and from the focus group discussions with the second and third years were used to construct a survey in order to interrogate the various factors shown in Figure 1. The aim of the questions was to discover how important or prevalent each factor was in shaping the first-year students' perceptions of physics. The survey was completed by the first-year physics class and quantitative data was collected based on a 5-point Likert scale.

Numbers one to five were assigned to the responses, one denoting strongly disagree and five strongly agree. Some statements were stated in the negative to discourage students from marking the same answer repeatedly, these response scores were inverted when calculating the average.

3. Results

At the outset it should be noted that due to the small sample size, no definitive statements can be made about the results. Only 25 first-year students out of a class of 41 completed the survey. It was therefore used as a general indicator of possible issues, and further more comprehensive studies will be conducted in the future.

A summary of all the responses, grouped together by each factor in each domain is shown in Figure 2. Four different colours are used, red, green, blue, to represent the domains and yellow to represent study skills. An inspection of averages for each domain shows that the affective domain is the dominant domain.

Correlation coefficients were calculated for all factors across all domains against students' performance (school and university marks). The coefficients were all below $r = 0.5$. The lack of correlation could imply that school marks and school attended are not good indicators of how students will perform in university physics.

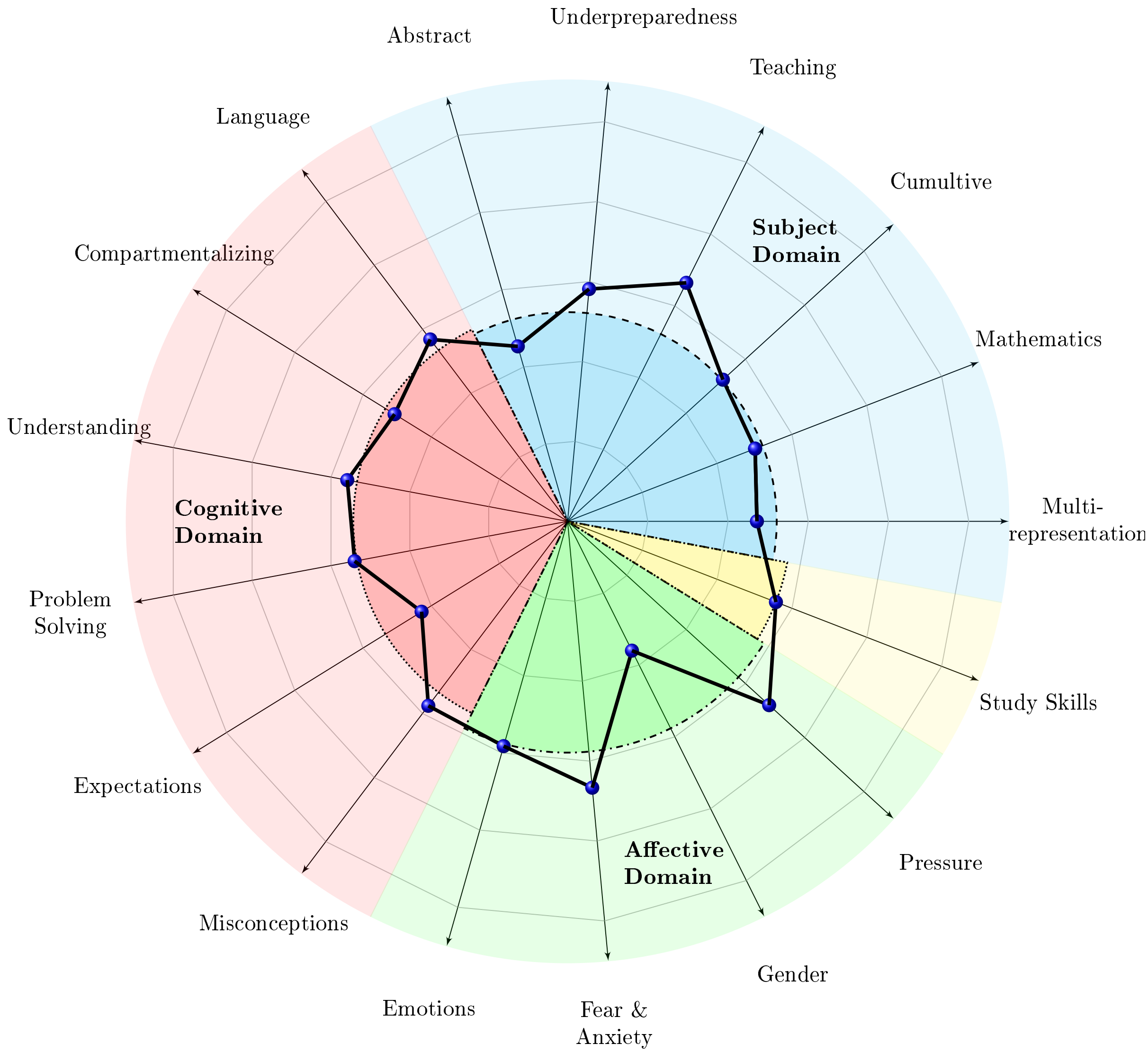

Figure 2. Diagram showing the three domains. Each point is the average for the factor which is labelled on the edge of the diagram. The darker background colour outlined by a black dotted line shows the average for each domain. The responses were calculated on a scale of 1 to 5, strongly disagree to strongly agree and are indicated by the grey concentric rings. The inner most ring indicates strongly disagree, moving outward to strongly agree.

3.1. The subject domain

The role of mathematics From Figure 2 it can be seen that the mathematics factor score lies slightly below the domain average, meaning that students do not seem to regard mathematics as a major contribution to their difficulties. It is somewhat surprising that first-year students do not find mathematics a concern despite the fact that all lecturers raised students lack of basic mathematics skills as one of the most pressing concerns.

In studying the responses to the individual mathematics factors it was seen that students indicated that they struggle to solve for a variable in a complicated equation. Their responses further revealed that they agree with the second and third years in that they find it hard to connect mathematics to the real world and that even though they know how to do the mathematics, they struggle to do the physics.

The cumulative nature of physics Although students in the focus groups recognised the importance of the cumulative nature of physics, the cumulative aspect falls below average relative to other factors in the subject domain (seen in Figure 2). To further interogate their understanding, one or two students from each year were asked to construct flow charts to show the cumulative nature of physics.

The chart created by first-year students included unconnected lists of courses, this may indicate that first-year students compartmentalise their knowledge to a greater extent. The second-year's chart showed sections of physics which were clearly separated. The students drew more connections than the first-year students, and they included fields of physics they have not studied. This may reveal that students continue to compartmentalise their knowledge but they do realize there are relationships between domains in physics. The third-year students also categorised their chart. Their chart contained more relationship arrows. This shows that as students progress they are better able to see the bigger picture of physics.

The role of teaching The results of the survey show that half of the first-year students agreed or strongly agreed that sometimes lecturers make physics harder than it needs to be. This could be because the teaching of physics at Rhodes University places emphasis on the understanding of concepts.

Other factors Under-preparedness was raised as an issue but it was not sufficiently interrogated in this study. Further studies are being undertaken in the science faculty at Rhodes University.

In contrast to the academics, first year students did not emphasize abstraction and multi-representation as concerns.

3.2. The cognitive domain

It appears that first-year students generally do not find factors in the cognitive domain to be a concern, as is shown in Figure 2. This is seen by the fact that all the factor scores in this domain are less than 3, indicating that, on average, students disagreed that these factors were issues contributing to the difficulty of physics.

Expectations and misconceptions In contrast to the second- and third-year students, many first-year students said in the free-response questions that they "*enjoy physics because it explains how things work in nature and they see the applications in real life*". This contrast may be because more abstract courses are introduced and concepts are described in a more mathematical manner in later years.

Over half the class disagreed with the statement that "*Physics at university is not as interesting as I thought it would be.*" and no-one agreed strongly with it, indicating that at least some of their expectations where being met.

The particular questions asked on the misconceptions factor are:

Q5 : Some of the terms used in physics are confusing.

Q25 : There are some things in physics that seem very different from what I have experience in the real world.

Students answered these questions using the Likert scale and the average of their results are shown in Figure 2.

Understanding The responses showed that students seem willing to put in time to understand physics. All students realize that they need to know the work well. However, they struggle to find the time to understand the concepts when they are expected to produce numerous assignments. The assignments help understanding but the students often start by reading an assignment problem and then simply trying to find the relevant equation. Some argue that there is not enough time to review the chapter before attempting the problems. Students need to learn to manage their time better. However, some students said that sometimes the lecturers set unrealistic expectations on how much can be covered in a course.

In the free-response questions, the first-year students said that they are worried when "*things*" are not explained properly, that there are too many formulae and that they often do not know which is the correct formula to use in a given problem.

Compartmentalisation Compartmentalisation is not a grave concern to the first-year students. However, students would like a special mathematics course for physics and that they feel overwhelmed when they have to use information from other subjects to solve a physics problem.

Problem-solving The physics department at Rhodes University has implemented an explicitly taught problem-solving framework. In this framework, students need to understand the problem before they solve it and only then can they evaluate the problem. Evaluating strengthens understanding of the concepts, thus supporting a homogenous relationship.

The survey results suggest that students do not find problem solving an issue. This could mean that the problem-solving framework being taught in first-year is helping the students. It would be interesting to analyse the students' assignments over the year to see whether their problem solving skills improved with the new framework. This study is currently being undertaken.

Langauge First-year students agreed that it is difficult to understand the textbook but said that they understand the words and terminology. This appears confirms the lecturers' point that students struggle to read for comprehension.

Many of the results of the subject and cognitive domains in this study mirror the findings of a similar study presented in [13].

3.3. The affective domain

Emotions and pressure There are many factors external to the physics subject and students cognitive abilities. A large number (77%) of students said they had pressure on them to do well and 73% of students said they worry about financial, family or home stresses. Students were asked if physics makes them cry, the first-year students responded negatively to this statement. They become excited discussing physics with peers and they do not feel that it creates unnecessary stresses.

Fear & anxiety Over half the first-year students are worried about failing physics. However the responses from first-year students indicated that tests are not the most feared part about physics. Most of the first-year students indicated that they ask and answer questions in class. They also mentioned that physics does not make them more nervous than other subjects. Based on the link between student and lecturer competencies studied in Glaser [14], this seems to show that they perceive their physics lecturers to be competent and supportive.

Gender In contrast to a study done at Harvard [15], the data seems to indicate that there is no significant gender gap in the academic achievement between males and females in physics at Rhodes University. This was derived from analysing student marks from their final year of high school and first semester at univeristy for physics.

Figure 2 indicates that gender is not a significant factor that negatively affects the perceptions of physics. However a closer examination of the raw data reveals that a fraction of the students do feel isolated and pressure to prove themselves because of their gender. One student revealed that she experienced the most discrimination from peers. The lecturers at Rhodes University do not tolerate gender discrimination. It would be interesting to investigate gender discrimination between students and the effects it has on throughput rates and enrollment numbers.

3.4. Study Skills

Correlation coefficients between students' study skills and their response scores to other factors in this study were calculated. There was a high correlation between study skills and understanding and problem-solving abilities, $r = 0.83$ and $r = 0.70$ respectively.

The third-year students pointed out that different studying and problem strategies are needed for each course and that they need to adapt their approaches. It may take time to learn these strategies but lecturers still expect a high standard of work and understanding.

4. Conclusion

Definitive conclusions could not be drawn due to the small sample size. However, from the data collected it appears that the affective domain is slightly more dominant than the other domains (shown in Figure 2), with support, pressure and emotional factors being the largest contributors. This is interesting to note because many universities try to address students' cognitive and subject related difficulties. However, there is generally not a large emphasis placed on students' affective concerns.

In the subject domain it appears that students perceive teaching to be a concern, followed by language and then under-preparedness. In the cognitive domain the largest contributing factor was students' misconceptions of physics. Students' misconceptions can stem from under-preparedness. In further studies on under-preparedness, students' misconceptions should be taken into account.

There is a strong correlation between study skills and students' understanding and problem-solving abilities.

4.1. Suggestions for further research

As this is a pilot study it will be useful to use the insights and experiences learned to reformulate the current survey by taking more factors into account and refining the current statements. It would be interesting to implement the survey and analyse the results on a larger sample, over several years, at other universities across South Africa.

It would be beneficial to the science faculty if the survey and data analysis could be generalised and applied to other departments in the faculty. This would help departments cater to students interested in their fields.

The gender analysis results provide motivation to conduct a faculty-wide gender study, looking at gender discrimination between students and solutions in the science faculty.

Students seem to be under the impression that their mathematical ability is good whereas lecturers feel that it is not. This is clearly problematic and mathematical abilities and preparedness of first-year students need to be investigated.

4.2. Suggestions for the physics department

Recommendations for physics department that may improve first-year students' performance are outlined as follows.

- Provide video recommendations along with reading lists for each course.
- Consider teaching the mathematics required for the physics course before the course begins in order for the students to become comfortable with the mathematics needed.

- Consider extending a physics major course to a four year degree. This would allow concepts and courses to be covered in detail and allow students to engage with the material on a deeper level.

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