# Correlations between matriculation marks and mechanics misconceptions

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**Abstract.** In this proceeding we discuss the initial stages of how using 'dominant misconceptions', as derived from the pre-test part of the Force Concept Inventory (FCI) assessment tool, can give informative data on how to proceed with teaching practices on a classical mechanics course, as taught in the Physics Department of the University of Johannesburg (UJ). We also briefly discuss some language correlations between high school matriculation marks and FCI scores, and how this may prepare faculty members when considering their teaching andragogy. In conclusion, the academic and language backgrounds of students enrolled on classical mechanics courses at UJ can have an impact on pre-test ability.

## 1. Introduction

In a recent work by the authors, reference [1], we have looked through the 'misconception' lens at how undergraduate students on a classical mechanics course perform on the *Force Concept Inventory* (FCI) assessment tool [2–5]. The FCI is a 30-minute multiple-choice test comprised of 30 questions on elementary principles and applications of classical mechanics; *viz.* circular motion, Newton's three laws, etc. The recommended means of administering this assessment tool is as a strictly closed-book test held at the beginning of the semester (the *pre-test*), to provide instructors with an indication of their students' baseline mechanics skills. Students are not expected to prepare for the assessment and once the pre-test is completed it is not reviewed in class nor do students receive feedback on their attempts.

However, adaptive physics pedagogy/andragogy has become a topic of interest in recent years [6], with a particular focus on confronting persistent or 'dominant misconceptions' generally held by incoming undergraduate students as has been argued in references [7–13]. Martin-Blas et al. [10] and Bani-Salameh [12] have suggested that these flaws in understanding should be diagnosed as early as possible by looking at these 'dominant misconceptions' in the pre-test. If effective teaching is to take place [12], then a primary objective at the start of teaching mechanics is to identify these misconceptions. A number of diagnostic tools have been developed for the various physics sub-disciplines. A subset of these have been designed to gauge student comprehension at the onset of an introductory university course, and then to assess their progress at the end of the course.

As such, we shall discuss in this proceedings some further work we have undertaken with the first year undergraduates taking physics at the University of Johannesburg (UJ). In particular, we will see that for the 2021-2022 cohorts at UJ, see figure 1, questions 5, 11, 17, 19, 26 and 30 were the questions where dominant misconceptions lay. Note that questions 5 and 17 relate to questions on gravity (for example question 5 asks about the forces exerted on a circular frictionless channel), question 11 relates to Newton's third law, question 26 to Newton's first law and question 30 to impetus.*

Given these ideas we would like to ask the following research question: How do high school matriculation scores in mathematics, science and languages affect the pre-test scores of the FCI? Our preliminary investigations conducted with the first-year engineering and physics students at UJ in 2020 [1] seemed to support this, where one particularly popular incorrect response was that "a force in the direction of motion" was partially responsible for the action described in the corresponding FCI question. The belief that "motion requires an active force" was flagged as a misconception as identified in references [10, 12, 13].

In our present study, we have performed a question-by-question analysis on the FCI pre-test responses for the 2021 and 2022 first- year physics cohorts, with $N = 313$ students in the 2021 cohort and $N = 337$ students in the 2022 cohort, see tables 1 and 2.† We begin with a description of the student participants and the manner in which their responses were collected in section 2. We then present our results in section 3, with a focus on the 'dominant misconceptions'. We also include a preliminary look at correlations between matriculation marks and FCI scores in section 4, followed by conclusions and future work in section 5.

## 2. Methodology

Due to the ongoing nature of the COVID-19 pandemic, South African institutions of tertiary education were expected to function mostly – if not entirely – online [1]. The delayed release of the 2020 Grade 12 results further derailed the 2021 academic programme, with first-year academic activities only beginning on March $8^{\text{th}}$ at UJ in 2021, leading to a first semester shortened by several weeks and the pre-test deployment delayed until March, see table 1. The 2022 cohort started on schedule as can be seen from the February deployment of the pre-test in table 2.

With the permission of the various lecturers involved in each of the courses that participated in this study (see table 1 for details) and ethical clearance from UJ's ethics committee, we launched the FCI test via the Blackboard interface – using the valuable lessons learnt during lockdown where we found it became easier to deploy this inventory test online – and made it available to students for a total of five days, using the module page corresponding to each of the courses.

Whilst we shall leave this for future work, it is interesting to note that through this platform we were able to track student activity (to determine whether test-takers left the browser page during the course of the test), time their test attempt, and force submission after an allotted time. We were also able to make a test visible for a set period of time. For our data collection, we enabled these features to reduce cheating and to ensure students submitted their responses after 30 minutes. Once the deployment period was over and each class had completed the assignment, the data was downloaded and processed within a single Excel spreadsheet for each

* Access to this inventory and more information about other types of physics & astronomy tests can be found in reference [14] and at the following website https://www.physport.org/.

† In this case we include all students who sat the pre-test, regardless of whether they fully answered all questions or not.

**Table 1.** Course codes, their associated entry-level requirements (Grade 12 mathematics and physical sciences scores), FCI deployment period, number of student responses per class, and average scores for five first-year classes involved in the 2021 FCI pre-testing: $N = 313$.

| Course (Physics for...) | Ent. % Math. | Ent. % Phys. Sci. | Deployment period | Responses/ class | Mean (%) |
|---|---|---|---|---|---|
| PHYS1A1 (Majors) | 70 | 60 | 13/04 - 17/04 | 19/70 | 33.2 |
| PHY1EA1 (Physics Ext.: Sem1) | 60 | 50 | 09/04 - 13/04 | 187/306 | 30.1 |
| PSFT0A1 (Education) | 50 | 50 | 05/04 - 09/04 | 62/91 | 29.9 |
| PHYG1A1 (Earth Sci.) | 60 | 50 | 05/04 - 09/04 | 13/17 | 28.2 |
| PHYL1A1 (Life Sci.) | 70 | 50 | 07/04 - 11/04 | 32/64 | 28.6 |

**Table 2.** Course codes etc. as in table 1 for five first-year classes involved in the 2022 FCI pre-testing: $N = 337$.

| Course (Physics for...) | Ent. % Math. | Ent. % Phys. Sci. | Deployment period | Responses/ class | Mean (%) |
|---|---|---|---|---|---|
| PHYS1A1 (Majors) | 70 | 60 | 21/02 - 25/02 | 28/55 | 36.7 |
| PHY1EA1 (Physics Ext.: Sem1) | 60 | 50 | 21/02 - 25/02 | 176/250 | 26.7 |
| PHYG1A1 (Earth Sci.) | 60 | 50 | 21/02 - 25/02 | 9/9 | 33.3 |
| PHYL1A1 (Life Sci.) | 70 | 50 | 21/02 - 25/02 | 19/40 | 30.0 |
| PHYE0A1 (Engin. Phys.) | 60 | 60 | 24/02 - 28/02 | 105/500 | 33.3 |

of the individual classes. All data was anonymised in accordance with the requirements of the protection of personal information act.

In what follows we will present preliminary comparisons for the FCI pre-test data for the 2021 and 2022 cohorts at UJ. The analyses break down the responses for each question to look for 'dominant misconceptions' [10]. This can be very useful in gauging how an initial cohort, and indeed different subgroups, need different teaching pedagogies. We then also present some initial results relating to correlations between FCI performance and high school matriculation results (this was part of the ethics clearance which had been obtained for this work from 2021 onwards).

Note that in tables 1 and 2 'Ext.' refers to the extended courses, where students who do not meet entry-level requirements for introductory physics classes can complete a four-year Bachelor of Science in which the traditional first-year physics course is taught over a three-semester period. We have also included a third semester course result for comparison in table 1. In relation to both years (2021 and 2022) in tables 1 and 2 the number of students who sat the pre-test were 313 and 337, respectively. This is less than the number of students who take the course. For example, in table 2, the number of Engineering Physics students for 2022 was 500, but only 105 attempted the pre-test.

## 3. Pre-test analyses and results - 2021 vs. 2022

The preliminary analyses of the pre-tests for the 2021 and 2022 cohort at UJ, for each of the 30 questions, is summarised in figure 1. The green shaded % shows the percentage of students

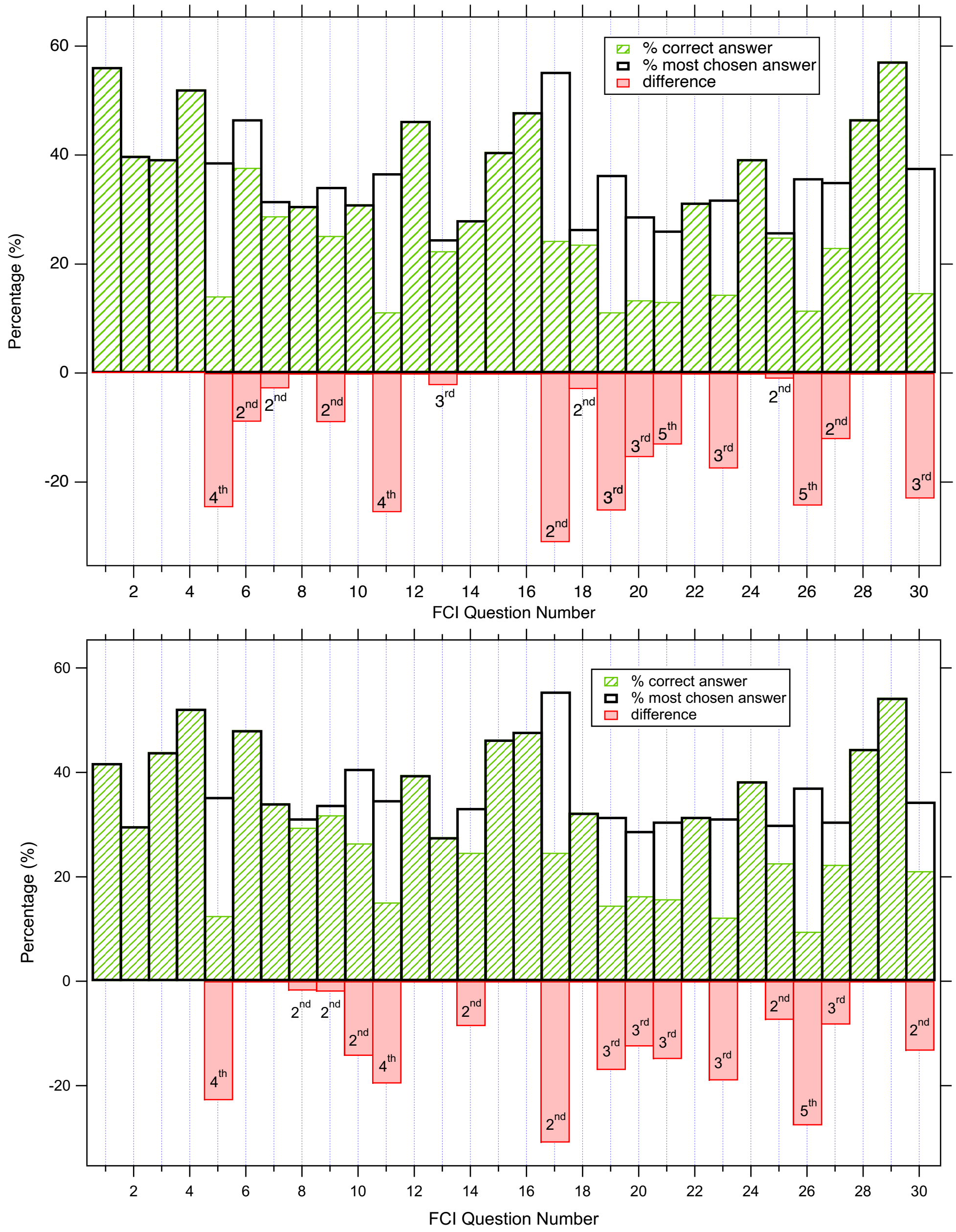


**Figure 1.** Comparison of pre-test scores for 2021 and 2022 cohorts. Top panel: Breakdown of pre-test questions for the 2021 UJ students sitting an introductory physics course, $N = 313$. The labels on the red % differences, such as $4^{th}, 2^{nd}$ etc., label the most commonly chosen (incorrect) response. Lower panel: Breakdown of pre-test questions for the 2022 students sitting an introductory physics course, $N = 337$.

who got the correct answer, with the black outline showing the % for the most commonly chosen answer. For example, questions $1-4$ have all of the responses as correct. The choices where the majority response was incorrect correspond to those questions with a larger red % difference showing that more students chose the wrong answer. For these cohorts of students this corresponded to questions 5, 11, 17, 19, 26, and 30, respectively. Given that this information was collected at the pre-test stage, the course instructors could attempt to adjust the teaching

**Table 3.** Pearson's correlation coefficients for different classes in the 2022 cohort. The course codes are discussed in table 2, where 'Eng' implies English was the main language spoken at home and 'Other' implies another language aside from English was spoken at home.

| Matric / Pretest | PHYS1A1 | | PHYS1EA1 | | PHYG1A1 | | PHYE0A1 | |
|---|---|---|---|---|---|---|---|---|
| Corr Coeff | Eng | Other | Eng | Other | Eng | Other | Eng | Other |
| Phys Sci | 0.375 | 0.683 | 0.125 | 0.314 | -0.945 | -0.445 | 0.060 | 0.303 |
| Maths | 0.147 | 0.707 | 0.338 | 0.220 | -0.979 | -0.559 | 0.562 | 0.521 |
| English | 0.293 | -0.157 | 0.214 | 0.103 | 0.645 | -0.614 | 0.099 | -0.054 |

and learning to try to reinforce a given concept as deduced form the relevant question.‡

These questions appear to show what Martin-Blas *et al.* call 'dominant misconceptions' [10] For example, question 5 focuses on circular motion and we can see here that this question was not well understood by most of the cohort. Given that this information was collected at the pre-test stage, the course instructors could attempt to adjust the teaching and learning to try to reinforce such a concept.

A comparison of tables 1 and 2 for the mean scores, and figure 1 for the amount of red % differences observed, allows one to infer that the 2022 cohort has performed better on the pre-test. Quite interestingly, the dominant incorrect answer (labelled in the red shaded region) is the same in all but a few of the questions.§ Besides using 'dominant misconceptions' we have also started to investigate correlations between high school matriculation results (in various subjects) and pre-test FCI results.

## 4. Correlations between high school matriculation marks and FCI pre-test scores

As well as considering 'dominant misconceptions' we may also look for correlations between high school matriculation results and the FCI pre-test. Table 3 summarises some of our initial investigations into correlations among the different cohorts for 2022. For example, 9 students were in the PHYG1A1 cohort and the number who spoke English at home was three. As such, the study could benefit from increased group sizes, and will be left for future work.

However, one can infer an overall trend that correlations between English scores and the FCI pre-test are more positive for students whose language spoken at home is English. This is in agreement with the observations made in reference [15], where FCI gains were found to have a dependence on English reading ability. Table 3 also shows that mathematics and physical sciences matriculation scores also have a positive correlation with pre-test scores. Though this is with an exception for PHYG1A1, which only had 9 students, in which case we cannot say too much here, due to the validity of the statistics for such a small sample.¶

## 5. Concluding remarks

In these proceedings, we have used the pre-test part of the FCI to evaluate the baseline comprehension of Newtonian mechanics presented to first-year students enrolled in introductory physics courses over a two year period from 2021-2022. From the method of 'dominant misconceptions' we are able to see how a whole cohort compares, see figure 1 for a comparison of 2021 and 2022 cohorts. By displaying a question-by-question breakdown on the pre-test we can see what % of each question is answered incorrectly and also confirm if similar cohorts answer

‡ It should be noted that the post-test and hence the gain generally shows improvement [5].

§ This may not just be that the 'misconceptions' are the same but also possibly that the design of the inventory itself is also slightly flawed, e.g., see reference [16].

¶ For reasons of brevity we have not included Life sciences PHYL1A1, although similar correlations are found.

with the same "wrong-answer" type, see figure 1. Quite interestingly both cohorts answered the same set of questions incorrectly, see figure 1. In particular, questions 5, 11, 17, 26 and 30. As such, these two cohorts share similar 'dominant misconceptions'.

We have also started looking at how possible correlations with given subjects in high school matriculation results can be used to predict how well a given student will perform. Although this work is in its preliminary stages, table 3 shows correlations between the different cohorts sitting first year classical mechanics at UJ; where a clear positive correlation can be seen for mathematics and physical sciences scores.‖ The subgroups for each cohort have been divided into English being spoken at home or another language spoken at home and in general we see a negative correlation for those whose main language is 'other'. The FCI does have different language versions, see the discussion of the PhysPort system in reference [14], but no Afrikaans, isiZulu, isiXhosa, and many of the other languages spoken in South Africa are not available.**

Although this is only a preliminary study, in relation to our recent work focusing on the 2020 cohort [1], we hope to combine our data from across all three years: 2020-2022 and then look at how high school matriculation performance data (as briefly discussed in section 4) correlates to student performance on the FCI and given the possible issues around the first languages of our participants, a translation of the FCI into all official languages of South Africa could be considered.

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‖ The smaller cohorts such as PHYG1A1 have smaller numbers making statistical inferences more difficult.

** The physics department at UJ is in general comprised of students from various diverse cultural and linguistic backgrounds, see for example [17].