Investigating the Nexus Between Physics Understanding and Spatial Anxiety Among First-Year Students

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ABSTRACT

Research has shown that spatial ability is important for success in STEM. Spatial ability is closely linked with mathematical ability, and as mathematics and conceptual understanding underpin the study of physics, an analysis of incoming physics students skill sets could show where improvements are needed in these areas. Affective factors of anxiety are also known to affect performance and confidence in these subjects, hence the reason for including these measures.

This study presents an investigation of the relationship between physics conceptual understanding, geometric thought and spatial reasoning abilities as measured by the Force Motion Conceptual Evaluation (FMCE), the Van Hiele Test, and the Purdue Spatial Visualisation Test : Rotations (PSVT:R) respectively. Measures of math and spatial anxiety are also employed. The tests were administered as part of an in-class session to a cohort of 1st year physics students.

The analysis shows a significant correlation between physics student's spatial ability and Van Hiele levels in this cohort of students. Spatial anxiety has a negative correlation with spatial ability, and it was significantly higher for female students compared to the male students. Math anxiety also has a negative correlation with Van Hiele levels, and was also found to be higher for the female cohort. This study could help to improve our understanding of first year students' abilities and related anxiety levels. This could potentially lead to more effective ways to educate students that fall into the low spatial ability and high anxiety levels, a group over-represented by females. Further research is necessary to make the sample representative.

1 INTRODUCTION

Physics knowledge underpins the study and practice of the engineering disciplines. Therefore, there is a strong rationale for investigating students' understanding of physics and other important concepts and cognitive skills for these domains, in order to help identify areas that students particularly struggle. As physics and engineering in particular has difficulty with obtaining a gender balance within the discipline, it is of particular relevance to investigate gender differences in physics understanding, and cognitive skills that are crucial to aid success in physics and engineering disciplines. Spatial ability has been consistently shown to be important for success in STEM disciplines [1-3] and particularly, many studies have shown there is a significant gender difference, most notably for spatial ability tests requiring mental rotation [4-6].

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Furthermore, studies show that students entering first year physics programmes lack fundamental conceptual understanding, and that even after instruction in the topics, very little if any improvement is often observed [7]. Consistent, large gender differences have been observed for physics concept inventories [8]. Another study demonstrated that even after interactive engagement techniques were employed in the classroom setting, this was not enough to eliminate gender differences in the FMCE [9]. As physics problems are often abstract in nature, and require mental visualization of complex phenomenon, spatial ability is important for understanding physics concepts, and to aid in the problem solving process [10].

Although possessing the necessary concepts and cognitive skills required for successful completion of studies within the physics and engineering disciplines is crucially important to aid success within the discipline, these are not the only factors that come in to play. Studies have shown that affective factors, such as math and spatial anxiety affect students' confidence and performance [11-13]. Again, large gender differences were observed, with females exhibiting higher anxiety levels, and lower confidence in their approaches to math and spatial tasks and problems [14]. As physics and engineering disciplines are inherently mathematical and spatial in nature, this is quite a cause for concern.

Stereotype threat is also another factor to consider in this context. Studies have shown that achievement gaps in various psychometric tests can be affected by the participants' negative stereotype views [15-17]. A landmark study showed that African American college students performed worse on an intellectual ability test compared to White college students of the same academic ability, when the test facilitators highlighted that the test was designed to diagnose intellectual ability. Another study also showed that a sample of females in first year of university performed worse on a mathematics test when they were told that the maths test shows gender differences, compared to the group that were told the test does not show gender differences [16]. However, it has been demonstrated that altering the testing conditions can have a significant impact on the performance of the participants [15]. When the test was presented as a diagnostic of intelligence, the African American students performed worse, compared to the White students. In contrast, when the test facilitation was designed to alleviate this stereotype threat condition, the two groups were found to have equal scores in the intellectual test [15]. Therefore, it is important to be aware of testing protocols and situations which could lead to stereotype threat arising, and therefore influencing the results obtained.

In this study, the aim is to investigate the levels of physics conceptual understanding, geometric thought, spatial ability, and anxiety levels in math and spatial situations for a sample of first year physics students. If the relationship between these variables is better understood in this context, then this could lead to improvements in teaching practice, and help to aid the female students in particular to overcome their anxieties and build confidence to succeed in STEM education. The research questions for this preliminary study are:

- What is the relationship between physics conceptual understanding, geometric thought and spatial ability for 1st year physics students?
- What are the gender differences, if any, for physics conceptual understanding, geometric thought and spatial abilities, and for math and spatial anxiety?

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2 SAMPLE AND METHOD

For this study, a class group of honours degree first year physics students were administered various concept, cognitive and affective factors tests, as part of an inclass session. This first year group consisted of 32 students. Due to class scheduling, it was not possible to administer all five tests on the same day. This would also likely have caused test fatigue for the students. Therefore data from 29 students out of the 32 that sat all five tests are presented and discussed in this paper. Out of these 29 students, 19 were male and 10 were female. 10 students had studied physics in second level at leaving certificate (end of secondary school exams), and 19 had no previous physics experience. The age range was between 18-23 years old. Ethical approval was granted for this study within the institution. The students were informed that the tests were part of a research study, and that the results would not affect their grades or position within the institution in any way. All students had the opportunity to read and sign an informed consent form for the study. The researcher administered the tests in class, adhering to the recommended protocol and time limit for each subsequent test.

In order to minimise the possibility of stereotype threat arising, the researcher was careful to emphasise that the tests administered were standard procedure for incoming first year students. The results from the tests aid the educators of the course to improve their teaching practice. The results do not affect their course grades or progression in anyway, and they have no obligation to participate. As the students entering third level would be highly unlikely to have previously come across the tests administered in this study, gender differences arising in these tests would not be common knowledge amongst this cohort. The tests were presented as reasoning and problem solving tasks. The students were encouraged to answer each question honestly. In this case, it was not possible to have a control group to check for the possibility of stereotype threat arising, and therefore this cannot be ruled out completely. However, the protocol for administering the tests was carefully designed to minimise anxiety, and to place focus on the benefits of the results of the study for the educators in order to improve their teaching practices. The informed consent form highlighted this, where the benefits of the study were discussed in terms of aiding the successful teaching of STEM subjects in third level education.

2.1 Instruments

For this study, two concept, one cognitive and two affective factor tests were used to gather the data. The FMCE was chosen as the measure for physics conceptual understanding, as this test is widely used in the literature, and includes a wide range of topics in mechanics [18]. This test consists of 47 multiple choice questions. For each question, a scenario is presented, with 7-9 possible choices and one correct answer per question. The PSVT:R was chosen to measure spatial ability, specifically mental rotation, as it is widely used within third level STEM student studies [19]. In each question, and 3D object is presented, and then shown with a particular rotation applied to this object. Then a second 3D object is presented, where the exact same rotation must be applied to the second object, in an identical manner to the first. The correct orientation of the second object must then be chosen. This test consists of 30 multiple choice questions, with each question having five possible answers to choose from.

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The Van Hiele test [20] was chosen to measure the level of geometric thought, based on the Van Hiele Theory [21]. Many other studies have used this test in conjunction with the PSVT:R, to investigate relationships in various contexts. Mathematics and spatial ability are known to be closely linked [22], and geometry is particularly spatial in nature, thus the reason for choosing this measure. The test consists of 25 multiple choice questions, with five possible choices. The questions are grouped in five sets of five, where each set of five questions represents the geometric thought required to reach each Van Hiele Level, i.e. the first five questions represents Van Hiele Level 1, and so on. No numerical mathematics is required to answer the questions.

The sMARS (Shortened Mathematics Anxiety Rating Scale) was chosen as the measure of math anxiety, as there is a wide range of scenarios presented that are relevant for this cohort of students [23]. This test consists of 25 multiple choice questions, with five possible answers. In each question, a mathematically related scenario is presented. The answer selected is based on the test-takers' level of anxiety they would feel, if they were in the same scenario presented. The answers are on a five point scale, were A represents "*Not at all*" anxious, and E represents "*Very much*" anxious. The newly developed Spatial Anxiety Questionnaire was chosen as the measure of spatial anxiety [11]. This test was chosen, as there is quite a limited number of spatial anxiety measures to choose from, and this test is more comprehensive and similar in nature to the mathematics anxiety test selected. This test consists of 24 multiple choice questions, with five possible answers. In a similar manner to the sMARS test, the test-taker is presented with a spatially related scenario. The answer selected is based on the test-takers' level of anxiety they would experience if they were in the same scenario. Again, this is on a five point scale, with A representing "*Not at all*" anxious, and E representing "*Very much*" anxious.

The nature of the concept and cognitive tests are inherently different to the affective factor tests. The data obtained for the affective measures are self-proclaimed, and therefore the results must be interpreted accordingly. In contrast, the concept and cognitive tests assumes the data obtained is valid and reliable as there is a correct response for each question. This holds if each student endeavoured to answer correctly, and did not resort to randomly guessing. This is different from the affective tests, as there is no correct answer for each question. Even if two students select the same responses, this does not mean that they have equivalent anxiety levels.

3 RESULTS AND DISCUSSION

For this study, the variables were examined to investigate if gender differences existed for the five different measures. *Table 1* shows the mean values in percentages (except for Van Hiele Level results) of the variables, separated by gender.

Table 1: Comparisons of means for FMCE, Van Hiele, PSVT:R, sMARS and Spatial Anxiety by gender.

Test	Male			Female					
	n	Mean	SD	n	Mean	SD	t-test	Sig (2-tailed)	Cohen's d

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FMCE	19	28.11	17.19	10	20.00	3.779	1.967	0.062	0.65 (large)
Van Hiele	19	2.79	0.976	10	1.80	1.32	2.299	0.029	0.85 (large)
PSVT:R	19	75.61	20.00	10	47.33	22.65	3.460	0.002	1.32 (large)
sMARS	19	19.28	11.90	10	30.08	11.04	-2.378	0.025	-0.94 (large)
SAQ	19	25.27	14.60	10	39.38	16.64	-2.358	0.026	-0.90 (large)

Table 1 shows that the male students for this first year cohort on average have higher physics conceptual understanding, Van Hiele levels, and spatial ability scores. Where the female students on average have higher math anxiety, and particularly, higher spatial anxiety within this cohort of students.

An independent sample t-test was then performed to determine if these gender differences were significant. In terms of the concept and cognitive factors, the results for physics conceptual understanding showed that there was no significant difference, although the results were approaching significance at the 0.05 percentile. For both the Van Hiele levels of geometric thought and for spatial ability, there was significant gender differences. These findings highlight that the female students are lagging behind the male students when entering a third level degree programme in physics, in terms of these abilities that are crucial for success in their field of study. Now turning to the affective factor measures, the results showed that there were significant gender differences for both the math and spatial anxiety. These findings suggest that the female students in this study have significantly higher anxiety levels when presented with situations and tasks regarding maths, and particularly, with situations and tasks regarding spatial reasoning. These are interesting preliminary findings for educators, as we must ensure that the female students are being exposed to math and spatial tasks in such a way that they can build confidence in tackling these type of problems encountered in physics and engineering disciplines. However, this sample is very small and therefore not representative of first year physics students in general. It is also not possible to verify that the affective factor measures are measuring anxiety levels affectively, as these tests are based on self-proclaimed data.

These results indicate that the female students are entering third level at a disadvantage in terms of the concept and cognitive skills required, and this, paired with the high anxiety levels surrounding math and spatial tasks could lead to a lack of confidence in ability to complete their physics programme. These preliminary findings are pointing to possible barriers for women in physics, as if the aim is to help improve the way we teach for this group of students, the high anxiety–low spatial ability cohort, we need to recognise this is potentially a current issue in our classroom, particularly for the female students. Further research is required to reach any substantial conclusions, as the sample is too small in this study. However, these preliminary results are similar to findings from previous studies, and therefore support a rationale for further research in this area. A correlation matrix was then produced for all five concept, cognitive and affective measures. *Table 2* below shows the correlational relationships between the variables.

Table 2: Correlations for FMCE, Van Hiele, PSVT:R, sMARS, and Spatial Anxiety.

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	n	Van Hiele	PSVT:R	sMARS	SAQ
FMCE	29	.228	.106	-.340	.134
Van Hiele	29		.478**	-.560**	-.263
PSVT:R	29			-.340	-.425*
sMARS	29				.519**
SAQ	29				

The results show a moderate positive statistically significant correlation between Van Hiele level and spatial ability, and a negative correlation between Van Hiele level and math anxiety. There is a positive correlation between spatial anxiety and math anxiety. There is a negative correlation with spatial anxiety and spatial ability. There is a low negative correlation between math anxiety with physics conceptual understanding and spatial ability, approaching significance. There is very little to no correlation with physics conceptual understanding and spatial ability. *Fig. 1.* Below shows the relationship with a scatter plot.

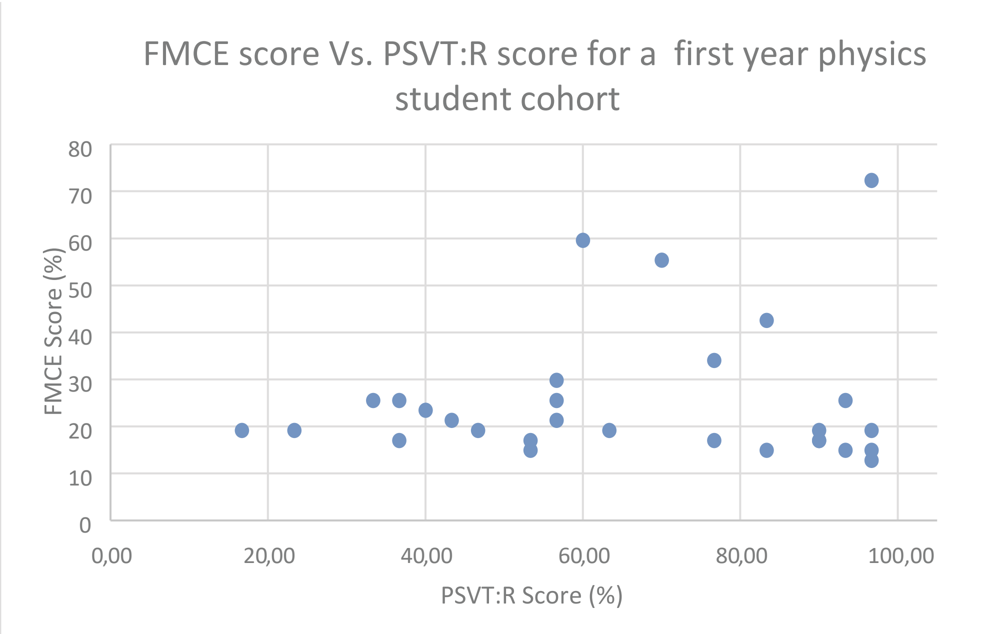

Fig. 1. Scatter plot showing the relationship between FMCE and PSVT:R Scores.

It can be seen in *Fig. 1.* that most of the FMCE scores are below the 25% mark. Where for the PSVT:R scores, there are many more scores at the middle and higher end of the spectrum. However, there are no students that scored highly on the FMCE with a poor score on the PSVT:R. The students that performed well on the FMCE also scored relatively well on the PSVT:R, with these data points shown in the top right

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quadrant in *Fig. 1.* There are no data points in the top left quadrant of the graph. In other words, there are no students that possess a high level of conceptual knowledge of physics, while having low spatial ability scores. This finding does align with a previous study which found similar results [24]

4 CONCLUSION

The findings from this preliminary study show gender differences favouring male students were found for spatial reasoning and geometric thought. In terms of the physics conceptual understanding measure, no significant gender differences were observed. However, the results were approaching significance at the 0.05 percentile. These findings could indicate that male students entering a first year physics degree programme have an advantage over the female students. Further research is needed to determine whether these findings hold for a larger sample. Gender differences were also found for both of the affective factor measures. The female students were found to have higher anxiety levels in both math and spatial related situations and tasks. This could imply that female students lack confidence in approaching these types of problems, compared to the male students, and thus, are at another disadvantage within this first year physics cohort. As physics and engineering disciplines require complex problem solving, often requiring spatial representation of various parameters and phenomenon, this would appear that the male students have an advantage over the females participating on the course. Although, the preliminary findings are only indicative at this stage, and further research is needed to determine whether these trends still hold for a larger sample of the first year physics cohort.

The correlational analysis showed preliminary relationships between the variables measured. The findings indicate that one's ability in spatial reasoning is related to one's ability in geometric thought, to some extent. The findings also indicate that if one has higher levels of anxiety in situations related to mathematics, or performing mathematical tasks, one is more likely to perform worse on the geometric thought test. This was also found for anxiety related to spatial situations, where one with higher spatial anxiety levels would be more likely to perform worse on a test of spatial reasoning. Furthermore, if one has a higher level of mathematics anxiety, one is more likely to also have a higher level of spatial anxiety.

As the gender balance in physics and engineering disciplines is a topic of concern, with many more male students than female students in these disciplines, this is particularly relevant as an area that needs further research in order to address these apparent deficits in female students' spatial ability and confidence within the disciplines. Further research would be beneficial in order to make the study much more representative for first year physics students by increasing the sample size substantially. It is not possible to draw substantial conclusions from this study, as it is limited by the sample size and the types of test instruments employed. However, a refinement of the methods used, and a substantial increase in the sample size will be a beneficial addition to these preliminary findings. In order for our teaching practice to improve and facilitate inclusivity, we need to recognise the barriers that are facing our female students, so that we can assist this student cohort to overcome any obstacles and flourish within the physics and engineering fields.

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