Factor Composition of Mathematics Anxiety in Undergraduate Mathematics and Physics Students

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Abstract

Mathematics knowledge is necessary for academic success in many subjects like Physics and Chemistry and across all levels of education while also being an important thinking and problem-solving skill for efficient functioning in everyday life. However, research [1, 2] has shown nervousness and worry experienced when students across ages are faced with numerical problems during their education [2, 3] or adults in their everyday life [1]. This, in many cases, has been suggested to be the result of mathematics anxiety [4], a negative emotional reaction to mathematics that includes feelings of tension and nervousness that interfere with the manipulation of numbers and the solving of mathematical problems. The impact high levels of mathematics anxiety can have especially on students include decreased mathematics performance, confidence, and motivation [5, 6]. Highly maths anxious students also experience mathematics avoidance at multiple stages including avoidance of mathematics studies when given the option and choosing careers with fewer mathematics components [7, 8]. This mathematics anxiety and impact it has are not an uncommon phenomenon even among college and university students studying academic disciplines that are either primarily mathematical, or are considered branches/subfields of mathematics, or involve mathematics as an integral component of the programme of studies (which has been referred to as STEM or STEM-related disciplines) [8]. This paper reports on the findings of a quantitative study examining this phenomenon of mathematics anxiety in university students studying mathematics and physics at an undergraduate level at a university in the UK. The purpose was to evaluate and test a mathematics anxiety measurement to identify barriers to the learning of mathematics at an undergraduate level. Factor analysis yielded a revised four-factor model of mathematics anxiety comprising an evaluation component, a learning component, a social element, and a novel factor unique to specialist students being a routine component. Results show that mathematics anxiety remains a grave concern and barrier to learning mathematics and the natural sciences, even among undergraduate students, who have chosen to study Physics and degrees with mathematics constituting the major component of their studies. Findings also show that gender differences, often reported in studies with primary and secondary school students, remain consistent in specialist undergraduate students. Recommendations for targeted mathematics anxiety support are also reported.

Keywords: Physics Education, Mathematics Education, Mathematics Anxiety, Mathematics Confidence, Mathematics Learning, Higher Education

1. Introduction

Mathematics knowledge is necessary for academic success in many subjects across all levels of education and an important thinking and problem-solving skill for efficient functioning in everyday life. In Science, Technology, Engineering, and Mathematics (STEM) Higher Education (HE), mathematics knowledge is an important component in undergraduate courses, since most, if not all, syllabi are very closely based on the development and application of this mathematical knowledge and thinking. Thus, this knowledge constitutes a factor of crucial importance both for students' success in their studies as well as a successful future career inside, or outside, STEM [9].

Despite this importance of mathematics knowledge and its application, research into academic success in shows that when students are faced with numerical problems during their education the often experience nervousness and worry [2, 3] This, in many cases and regardless the level of education, has been suggested to be the result of students experiencing mathematics anxiety [4, 9], a negative emotional reaction to mathematics defined as “feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations” [10, p. 551].

The impact of high levels of mathematics anxiety includes decreased mathematics performance, confidence, and motivation [5, 6]. Highly maths anxious undergraduate students also experience mathematics avoidance at multiple stages including avoidance of mathematics studies when given the option and choosing careers with fewer mathematics components [7, 8]. It is also reported that reactions of negative nature and numerical confidence are the most salient dimensions of mathematics anxiety in in HE across multiple disciplines, including health care professions and the social sciences [5. 9].

Students’ mathematics anxiety has been conceptualized as being multifaceted across levels of education with subject-specific research in HE also showing a number of different components. Among the different components, test/evaluation and class anxiety were found as the greatest sources of interacting with mathematics learning of university students [11]. The intercorrelation of these different components with mathematics learning and the relationship itself of mathematics anxiety with mathematics learning on Maths and Science students have not yet been studied widely.

1.1 Study Aim and Purpose

Mathematics anxiety and mathematics learning has been relatively well-studied and the negative associations between the two has been observed among HE students as discussed above. Nevertheless, there are fewer studies in Physics and Mathematics HE education, while several un-investigated areas in this specific HE area exist and that the present study addresses.

It remains unclear what of the different components of mathematics anxiety moderate the relationship with mathematics learning and the extent to which gender differences found mainly in primary and secondary education perpetuate in HE. The aim of the work reported on this paper was to provide insights into the different components of mathematics anxiety. The purpose was to evaluate a mathematics anxiety measurement on the perceived mathematics anxiety of Mathematics and Physics undergraduates while also applying this to identify different components of mathematics anxiety which pose barriers to the learning of mathematics in HE and to detect gender differences.

2. Methods

This study was designed to detect differences in the components of mathematics anxiety affecting mathematics learning among Mathematics and Physics undergraduates in a publicly funded university in the UK. It was also designed to investigate whether Mathematics and Physics undergraduates’ different components of anxiety correlates with their gender.

2.1 Participants

Participation was voluntary and the project was approved by the relevant ethics committee of the institution the research was conducted in. All undergraduate students, including integrated masters’ students, enrolled in the School of Mathematics and Physics were invited to participate in the study.

2.2 Procedure and Materials

Participants provided a hard copy of the survey where they were first asked to consent to the study. They were then given 2 hours to consider their participation to the study and then complete the survey. 126 students participated in the study, 84 males and 42 females. Students were enrolled in Mathematics (n=79), Physics (n=32), or a dual honours course (n=14). These proportions are representative of the wider School of Mathematics and Physics.

Mathematics anxiety was measured using the Mathematics Anxiety Scale–UK (MAS-UK) [12] specifically developed for undergraduate students but not exclusively for Physics and Maths students the MAS-UK scale is evaluated and tested for in this study. The scale comprises 23 statements concerning situations involving mathematics in a wide range of settings. For each statement participants are required to respond by indicating how anxious they would feel on a 5-point Likert-type scale, ranging from “1 = not at all” to “5 = very much”. The scale also has exceptionally high internal consistency (α = .96) and test-retest validity.

2.3 Data-analysis procedures

The results of the survey data were entered into IBM SPSS software version 27.0 for statistical analysis. AMOS software version 28 was used for confirmatory factor analysis. Mann-Whitney U-tests were used to assess binary gender differences between male and female students and Kruskal-Wallis H tests were used to assess course-level differences. Post-hoc tests, were conducted using Mann-Whitney U-tests. Non-parametric tests were used as the data was not normally distributed ($p > .05$)

3. Results

3.1 Confirmatory Factor Analysis

Confirmatory analysis of the original three factors using maximum likelihood estimation resulted in a large and significant chi-square statistic, $\chi^2(227)$ =497.06, $p < .001$. However, and because chi-square is sensitive to sample size [13] and nonnormality [14] Comparative Fit Index was calculated. The value of CFI was 0.77, indicating a less than adequate sampling fit, and root mean square error of approximation (RMSEA) = 0.10 (90% confidence interval [90% CI] = 0.90 to 0.114), which is greater than the 0.08 cut-off for an adequate fit [15] indicate the initial CFA model is not ideally suitable for further analysis. To ascertain if the three-factor model remained the most suitable model for the specialist sample, PCA was conducted anew. Exploratory factor analysis using a varimax rotation conducted which in this sample yielded an initial four factor model. A high Kaiser–Meyer–Olkin measure (KMO = .857) indicated that sampling adequacy was met, and very low values in the diagonal of the anti-image correlation matrix support the suitability of the data for factor analysis [15].

Initially, using Kaiser’s criterium of extracting eigenvalues greater than 1, four factors were extracted. Based on the suggestion that factor loadings in excess of 0.45 can be considered good [16], the pattern matrix was explored for factor loadings 0.45 or higher. Two items did not load on to any factor, “Reading the word ‘algebra’”, and “Working out how much your shopping bill comes to”. These two items contain the lowest variances and the lowest means of any items. All students studied two mandatory algebra modules therefore this was expected. Both items were removed, and PCA continued to yield a four-factor model, the rotated components are shown in Table 1.

3.2 Factor labelling

The first component comprises of items that focus on everyday mathematics including general social situations it is labelled Social Mathematics Anxiety (SMA). This interpretation is supported by the literature where similar factors have also been identified [12-14]. The second component comprises items that focus on learning mathematics and the wider educational environment, it is labelled Learning Mathematics Anxiety (LMA) This interpretation is widely supported in the literature where numerous studies [16-18] have identified a similar component in undergraduate students. The third component comprises items that focus on the assessment and evaluation of mathematics and is labelled Evaluation Mathematics Anxiety (EMA). This component has also been identified in other studies [16-18] using different scales.

The fourth and final component comprises four items that focus on basic mathematics skills and routine mathematics-based tasks. This unique identification of a Routine Mathematics Anxiety (RMA) appears unique to specialist mathematics and physics students and may be considered a sub-factor of SMA. Students whose courses have a high degree of mathematics content view some elements of mathematics are routine and commonplace.

Table 1. The four rotated components and factor loading of each of the questionnaire items.

Items	Factor Loadings			
	1	2	3	4
Factor 1: Social Mathematics Anxiety				
Q22: Working out how much change a cashier should have given you in a shop after buying several items.	0.831			
Q14: Deciding how much each person should give you after you buy an object that you are all sharing the cost of.	0.662			
Q4: Being asked to add up the number of people in a room.	0.628			
Q2: Adding up a pile of change.	0.624			
Q1: Having someone watch you multiply 12 x 23 on paper.	0.624			
Q7: Being asked to calculate £9.36 divided by 4 in front of several people.	0.604		0.531	
Q8: Being given a telephone number and having to remember it.	0.563			
Q21: Being asked to calculate three fifths as a percentage.	0.509			0.467
Factor 2: Learning Mathematics Anxiety				
Q12: Listening to someone talk about mathematics.		0.863		
Q16: Watching someone work out an algebra problem.		0.847		
Q15: Reading a mathematics textbook.		0.770		
Q17: Sitting in a mathematics class.		0.764		
Q20: Watching a teacher/lecturer write equations on the board.		0.554		0.472
Factor 3: Evaluation Mathematics Anxiety				
Q23: Being asked a mathematics question by a teacher in front of a class.			0.829	
Q3: Being asked to write an answer on the board at the front of a mathematics class.			0.815	
Q18: Being given a surprise maths test in a class.			0.657	
Q6: Taking a mathematics exam.			0.629	
Factor 4: Routine Mathematics Anxiety				
Q19: Being asked to memorize a multiplication table.				0.709
Q5: Calculating how many days until a person's birthday.				0.668
Q10: Calculating a series of multiplication problems on paper.				0.659
Q11: Working out how much time you have left before you set off to work or place of study.				0.459

Loadings of less than 0.45 were suppressed [12]

3.3 Gender Differences

For the main sample, overall mean mathematics anxiety was 45.53 (SD = 12.89) substantially lower than the original validation sample of 78.79 (SD = 26.37). This is because the original sample included undergraduate students from a wide range of faculties including, for example, Health and Design. The specialist sample in this study only includes student who have chosen to study mathematics or physics so one would anticipate lower levels of mathematics anxiety. Internal consistency of the specialist sample was also very high (α = .91). Gender differences are reported in Table 2.

Table 2. Gender Differences between the different mathematics anxiety components

	Males		Females				
	M	SD	M	SD	U	z	p
UK-MAS	42.73	11.89	51.29	13.11	3.52	114	<.001
EMA	12.70	4.25	15.85	3.21	933	3.80	<.001
LMA	6.88	2.72	8.00	3.78	1344.5	2.26	.024
SMA	14.22	4.75	16.78	6.05	1225	2.45	.014
RMA	6.66	2.84	7.71	2.88	1304.5	2.14	.033

Gender differences were calculated using Mann-Whitney U-tests as the sample was not normally distributed.

Differences between mathematics, physics, and dual honours students were assessed to explore possible differences between courses. Kruskal-Wallis tests are reported in Table 3. Significant results indicate the presence of course differences however post-hoc analysis using Mann-Whitney U tests confirm no significant differences between mathematics and physics students. Dual-honours students reported lower levels of mathematics than the single-honours students in the overall scores and the social and learning subscales.

Table 3. Differences of the anxiety components between mathematics, physics, and dual honours students

	Mathematics		Physics		Dual Honours			
	M	SD	M	SD	M	SD	H(2)	p
UK-MAS	46.48	12.19	47.41	14.77	37.36	8.86	7.24	.027
EMA	14.27	4.06	13.22	4.37	11.00	4.08	7.72	.021
LMA	7.49	3.39	7.34	2.89	5.86	1.75	5.24	.073
SMA	14.96	4.98	16.44	6.91	11.86	3.35	6.34	.042
RMA	7.01	2.88	7.47	3.14	6.07	1.90	1.90	.386

Course-level differences were calculated using Kruskal-Wallis tests as the sample was not normally distributed.

4. Conclusions

Factor analysis yielded a four-factor model: social mathematics anxiety, learning mathematics anxiety, evaluation mathematics anxiety, and a novel routine mathematics anxiety. The new factor appears unique to specialist STEM students who consider some aspects of mathematics so routine they may no longer form part of learning mathematics. Therefore, studies of mathematics anxiety in university Maths and Physics (or STEM related more generally speaking) students should not use unmodified mathematics scales which do not account for their increased ability, and appreciation of mathematics. Significant binary gender differences were shown for the unmodified UK-MAS and each of the four new components. Female students consistently reported higher levels of anxiety than their male classmates. These gender differences are consistent with the wider literature which repeatedly evidences a binary gender difference in mathematics anxiety [16-18].

The study findings also indicate significant gender differences among undergraduate Maths and Physics students, who have chosen to study degrees with a significant mathematics component. Comparisons between Mathematics and Physics students yielded very similar results suggesting the findings may be generalisable to wider STEM, and STEM-related students such as Chemistry, Biology, or Medicine. More thorough examination is required to understand why this gender difference still exists among undergraduate STEM students and what intervention and support programmes could be introduced to help mitigate the effects of mathematics anxiety.

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