XVIII ICIEOM 2012
International Conference on Industrial Engineering and Operations Management
Guimarães - Portugal
July 9 - 11, 2012

Mathematics achievement in engineering: an exploratory study with MIEGI students

Manuela Alves*, Cristina S. Rodrigues*, Ana Maria A.C. Rocha*

*Algoritmi R&D Centre, School of Engineering, University of Minho, Campus of Gualtar, 4710-057 Braga, Portugal

Email: manuealves@gmail.com, crodrigues@dps.uminho.pt, arocha@dps.uminho.pt

Abstract

Mathematics is a discipline that appears on the syllabus of many courses, including courses in engineering, where it is an essential discipline to the formation of all future engineers, whatever their field of study and work. Despite that, engineering students tend to reveal difficulties with courses based on mathematics. The factors that influence learning mathematics have been the subject of study for several researchers around the world. Researchers attempt to identify variables that explain mathematics achievement, but fail to address university students.

In this paper, we present the results of an exploratory study based on industrial engineering students of University of Minho, concerning their grades in the courses of statistics and numerical methods. The preliminary results show that gender is an unexpected and significant factor.

Keywords: Mathematics achievement, mathematics learning factors, industrial engineering, Minho, gender

1 Introduction

Engineering plays a significant role in the modern world since it is always presented in day to day activities concerning construction, computers, technology, energy, electronic devices, and manufacturing process. Many aspects of engineering activity comprehend the correct problem formulation and analysis, and the choice of the adequate method to resolve it.

Engineering courses require the awareness of mathematical concepts. During the course, students learn and consolidate basic mathematical principles in order to solve practical problems.

As part of their formal undergraduate training, engineering students should enhance knowledge in several mathematical based areas such as statistics, numerical methods, optimization and simulation, among many others. These are important techniques that engineering students need to know how to use.

Unfortunately, engineering students tend to struggle with their mathematical background and fail to recognize the importance of these subjects. According to our experience, student grades' reveals difficulties and motivational issues that go far beyond the required mathematical knowledge.

The present study aims to explore the mathematics achievement of graduate engineer students in the complex process of learning mathematical concepts, essentials to their future profession. More precisely, our present investigation will focus on mathematics achievements of statistics and numerical methods courses of the master of industrial engineer and management of University of Minho.

This paper is organized as follows. In Section 2 a literature review is presented, summarizing some of the factors that could influence the learning of mathematics. Following, in Section 3, we present the results of an exploratory study concerning statistics and numerical methods grades of industrial engineering students from University of Minho. In Section 4, we intend to present and discuss the most relevant conclusions and the future work.

2 Mathematics learning factors

Student performance is a concern for all educators and is an object of study that stands out in many academic papers. Due the importance of mathematics, its achievement and performance gained educators attention and is been an increasing field of study. Suther *et al* (2010) note, that there have been several researchers who have discussed the issue of learning mathematics and the factors influencing it.

The factors identified as influencing the learning of mathematics can be divided into two distinct groups: the demographic and psychographic factors. In the demographic factors we remark the gender factor that could explain differences in academic performance. In the psychographic factors we point out the personality, socio-cognitive aspects, the motivation, and the anxiety towards mathematics.

Following, we resume the most important ideas about these factors.

2.1 Demographic factors

Patterson *et al* (2003) refers in their study that since 1970s, gender has been investigated as a factor on which student performance and attitude toward mathematics differ. It is a general perception that boys are better at math than girls. However, Meelissen and Luyten (2008) state that studies on gender and mathematics show that the advantage held by boys over girls in mathematics achievement has diminished markedly over the last 40 years and gender differences in mathematics achievement are no longer a relevant issue. According to the same authors, research on gender and mathematics is often limited to the relationship between gender differences in attitudes toward mathematics and gender differences in mathematics achievement.

Patterson *et al* (2003) also refer that gender alone may not explain significant differences in performance when viewed in the context of multiple types of mathematical knowledge.

Accordingly to Meelissen and Luyten (2008:81):

> "... analysis of the results of studies conducted by the International Association for the Evaluation of Educational Achievement (IEA) on mathematics achievement showed a decrease in the number of countries in which the average achievement of boys in mathematics was higher than the average achievement of girls in this subject and an increase in the number of countries with an advantage for girls, a situation evident across both the primary and secondary levels of schooling. (Hanna, 2000)"

However, the gender difference in aptitude for mathematics can be explained by various factors, namely the preconceived idea, that is inculcated in the students early on, that boys have more aptitude for math than girls. Such as, Meelissen and Luyten (2008:84) say:

> "...societies generally regard mathematics as the domain of males, boys and girls receive different feedback on their mathematics achievement from people in their social environment, such as parents and teachers. As a consequence, boys and girls learn to value mathematics differently…
>
> …the relationship between attitudes and achievement is not clear and seems to be different for girls and boys. Although research on and theories relating to educational effectiveness link various school and class characteristics to achievement and attitudes, there is little information available to tell us if these factors have the same influence on the achievement and attitudes of girls and boys."

2.2 Psychographic factors

Educators and psychologists have given special attention to the relationship between personality characteristics, learning and academic performance. As stated in several studies, the learning of mathematics is related to personality traits and these are considered as predictors of students' mathematical ability. Citing Homayouni (2011:1):

> "In 21th century, researchers, teachers, and educators have examined and emphasized on some factors that can be important in learning, especially scholastic learning. In this domain personality factor and emotional intelligence are two concepts that have absorbed many attentions."

Homayouni (2011:2) also claims that:

> "Longitudinal data gathered by Mills (1997), over 10 years to ask whether personality traits were related to gender differences in long-term achievement in mathematics and the sciences. Math ability was the most significant predictor of long-term achievement in math and science for young women. Personality traits, when added to high math ability, increased the probability that young women would go on to pursue a career in math or science."

The socio-cognitive aspects are considered to be the most important in the process of teaching and learning. Related to these are also the emotional aspects (Sirmaci, 2010). Students' attitudes towards mathematics can generate positive or negative emotional responses in certain situations and are an indicator of success in this discipline. These attitudes are influenced by teachers' efficiency, the environment and the socio-psychological organization in the classroom. Studies have shown that teaching methods and teacher's personality influence students' positive or negative attitude towards mathematics (Sirmaci, 2010).

Torisu and Ferreira (2009) reported that methodology and affection are inseparable elements in education. By establishing emotional bonds with their students in the classroom, the teacher can influence them in positive ways, providing a pleasant environment and mutual trust. Such possibilities are directly related to the development of self-efficacy beliefs. There are several studies that show that self-efficacy is highly applicable to the educational context (Bandura, 2008).

Individuals can influence the course of events according to their interests and are active participants in the direction that their lives take, since it sets targets to be reached through paths chosen by themselves. Therefore, the school is the environment in which students spend most of their time. It is consequently natural that their behaviour is affected by the established relationship with the school community.

The self-efficacy is closely linked to motivation. Stronger self-efficacy beliefs of the individual, lead to a major motivation for performing tasks (Torisu & Ferreira, 2009, Walter & Hart; 2009).

Attitude towards mathematics can interfere with future self-esteem, identity formation and relationship with the utility of this discipline in the profession. The beliefs have an influence on the action, motivation and cognitive processes, the latter being related to the anticipation of consequences of actions and results. In the school context, these beliefs can affect students' motivation to perform tasks or avoid them, their reactions to their achievements, and even career choices (Neves, 2002).

Studies by Suthar *et al* (2010) declare that the mathematical beliefs and the results obtained by university students, show there are several evidences that students' beliefs about mathematics are crucial in the development of careers related to this discipline.

Bakar *et al* (2010) in a study of the relationship between motivation to achieve results and academic performance of college students show that motivation is the driving force behind our actions and affect our needs, desires and ambitions in life. Hence, there must be an effort by educators to stimulate the students' attitudes and motivation towards learning. This will lead them to achieve the best results.

According to Muir (2009), another factor that influences students' motivation for learning mathematics is the perception that parents have of mathematics. Many parents tend to value their own forms of doing mathematics over school mathematics', while many children value schools' form of knowledge over the parents' knowledge, hence demonstrating the potential tensions that may arise when engaging in mathematical tasks and assignments at home. There are several studies that concluded there were links between parents' attitudes, perceptions and beliefs about mathematics and children's attitudes and performance in mathematics (Muir, 2009).

There are consequences of the fact that students are anxious about mathematics, and this interferes with their academic achievement. Students who suffer from math anxiety typically refuse to enrol in courses or attending mathematics courses with a strong mathematical component that will condition their future career options. The mathematical anxiety is the result of low self-esteem and fear of failure (Kargar *et al*, 2010); Meelissen & Luyten, 2008). Students with a high degree of anxiety had less satisfactory academic results and when this anxiety was reduced, there was an improvement in their performance. Studies show that math anxiety can be reduced through the adoption of special methods of teaching and psychological intervention in the areas applicable to improving the educational curriculum practices.

Mathematic anxiety has also been associated to gender. Male students suffered less anxiety dealing with mathematic task than female and they are more confident and motivated at mathematic than female students (Vitasari *et al*, 2010). This statement is supporting that women have a higher incidence of depression, post-traumatic stress disorder, and other anxiety disorders

Mathematics anxiety among engineering students is manifested into five dimensions, namely: (a) Fell mathematics is a difficult subject; (b) Always fail in mathematics; (c) Always writing down in a mathematics class; (d) Anxious if don't understand; and (e) Lost of interest in the subjects of mathematics (Vitasari *et al*, 2010).

3 Exploratory research model

3.1 Elements

In our exploratory study, and due the course characteristics, we decided to concentrate in industrial engineering students from University of Minho.

> "Industrial engineering is commonly defined as the integration of machines, staff, production materials, money, and scientific methods." (Rouyendegh & Can, 2011)

The context of formation of industrial engineers has a strong mathematical component. The master in Industrial Engineering and Management (MIEGI) of University of Minho is no exception, and since it is a course oriented to the decision-making process, mathematics appears linked to all areas of study. In fact, in its syllabus arise curricular units such as: calculus, linear algebra, statistics, differential equations and integral calculus, numerical methods, operations research, among others.

For the purposes of the current investigation, and considering our experience as teachers, we are interested in students' achievement in statistics and numerical methods.

3.2 Methodology

The aim of this study is to explain academic performance and mathematical achievement of MIEGI students in the courses of Statistics I and II and Numerical Methods.

Based on courses grades, and using additional variables such as gender or former class frequency, we intend to explore differences on grades and to test the explaining capacity of several variables. This analysis will be made in the likeness of some research already done on the topic under study.

3.3 Results

In addition to descriptive statistics, we test whenever possible mean differences between grades. We also present the test results of a theoretical model using a regression procedure considering grades and possible explaining factors.

In order to present results, we decided to split the analysis into two parts considering course nature: (1) statistics and (2) numerical methods.

3.3.1 Statistics course

For the purposes of this investigation, we decided to analyze the two statistics courses together: Statistics I (2009/10) and Statistics II (2010/11). The total sample has 123 students [66 (Statistics I) and 57 (Statistics II)], mainly sex masculine (68.29%). Grades varied from 3.6 to 17.7 values, with a mean of 11.46 values and a standard deviation of 3.094.

To evidence gender effect, the boxplot illustrates differences between the two groups, specifically on the median and range (Figure 1). The boxplot also identifies two female students as outliers, *i.e.*, with results significant distant of the female group.

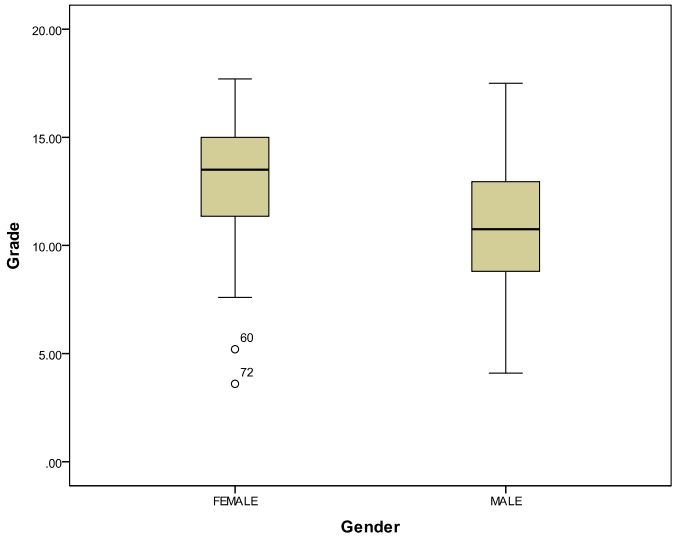

Figure 1 – Statistics Grade and Gender

When we explore grades in statistics course considering gender, results indicates mean differences, with female results superior than male. Female students have a mean of 12.93 values with a variance of 10.539. Male students present a mean of 10.77 values with a variance of 7.746.

Posterior independent t tests confirmed differences between mean gender results (significance level of 1%).

To perform the regression analysis to explain course grade, we defined an explanatory model with three independent variables: the gender (dummy variable 0=male, 1=female), the class attendance (number of attendance days), and former class frequency (dummy variable 0=no, 1=yes). Before regression procedure, we check data normality (Kolmogorov-Smirnov test, significance level of 5%). Regression results are presented in Figure 2.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.628[a]	.394	.379	2.43783

a. Predictors: (Constant), FORMER, FEMALE, CLASS_ATEND

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.703	.938		6.079	.000
	FEMALE	1.146	.491	.173	2.334	.021
	CLASS_ATEND	.672	.107	.699	6.257	.000
	FORMER	1.753	.911	.210	1.925	.057

a. Dependent Variable: GRADE

Figure 2 – Regression results for statistics course

Being a female is an important factor, and class attendance also impacts on course grade (an increase of one day of attendance, increase grade in 0.672 values). At a significance level of 5%, only the "former" class frequency is not significant.

The model has a lower capacity, since it only explain 39.4% of the variance of statistics grades (R^2=0.394). Nevertheless, it suggests that we need to improve model, studying additional variables proposed on literature (*i.e.* psychographic variables).

3.3.2 Numerical methods course

To explore numerical methods grades, the sample has the 56 students of the Numerical Methods course of 2010/11. Grades varied from 2 to 20 values, with a mean of 11.23 values and a standard deviation of 4.765. The gender distribution is: 53.57% male and 46.43% female.

When exploring gender differences, we realized that female students have better grades than male students:

- Female students: mean 14.52 values with a standard deviation of 2.441, and a minimum of 8 values
- Male students: mean 8.38 values with a standard deviation of 4.452, and a minimum of 2 values.

The boxplot analysis also illustrates gender differences (Figure 3). Female students present higher grades with lower variability, with significant visual differences comparing with male behavior.

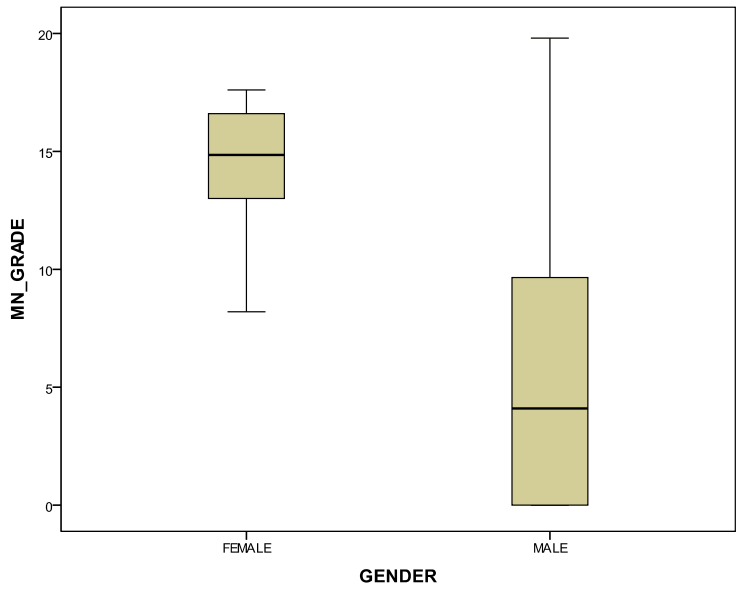

Figure 3 – Regression results for statistics course

Posterior independent t tests confirmed differences between mean gender results (equal variances assumed, significance level of 1%).

The regression analysis to explain numerical methods grade use as independent variables:

- The gender (dummy variable 0=male, 1=female), and
- The former Statistics II grade as a measure of previous mathematics achievement.

Regression results are presented in Figure 4.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.812[a]	.659	.645	2.762

a. Predictors: (Constant), EST2_GRADE, FEMALE

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.580	1.503		.386	.701
	FEMALE	3.954	.849	.431	4.657	.000
	EST2_GRADE	.804	.136	.547	5.913	.000

a. Dependent Variable: MN_GRADE

Figure 4 – Regression results for numerical methods course

The R square of 0.659 indicates that the considered model has explanatory power. Both variables are statistically significant (significance level of 1%). Beyond confirming the strong contribution of female condition in the grade, the model confirms the explanatory effect of Statistics II in the numerical methods course grade.

4 Conclusions

The world is becoming more competitive due to rapid economic growth and development of more and better technologies. This means that the sphere of education is hard-pressed to train students that are increasingly able to deal with this new reality. As a consequence, the standards of education and research in science, mathematics, technology and engineering are been rising accordingly. Mathematics is a discipline that appears on the curriculum of many courses, including courses in engineering, where it is an essential discipline.

The present study aims to explore the mathematics achievement of graduate engineer students in the complex process of learning mathematical concepts, essentials to their future profession. First, a literature review was done in order to identify the factors that could influence the mathematics performance of general students. Then our investigation focused on mathematics achievements of statistics and numerical methods courses of the master of industrial engineer and management of University of Minho.

We explore a linear regression model to predict student's grade in both disciplines. The results for the statistics course sample indicate significant gender differences, with female students presenting higher scores than their male colleagues. Class attendance also resulted as an important course success variable. Nevertheless the explanatory model requires improvements through the study and inclusion of additional variables proposed on literature (*i.e.* psychographic variables).

Numerical methods course results also highlight similar gender differences. The explanatory model, using only gender and former Statistics II achievement, resulted significant, *i.e.*, the two variables considered explain grade differences between students: being a female and had previous success (higher grade on statistics course) are important to predict numerical methods grade.

We consider these results as preliminary results, which require future confirmation with a bigger sample and a comparison with other engineering students.

As future work, our research will study the explanatory power of psychographic variables considered important in the literature. Whether students are in primary, secondary or higher education, motivation for learning mathematics emerges as the main factor influencing the acquisition and development of mathematical knowledge. This motivation is in turn influenced by the beliefs that students have about mathematics, and self-efficacy beliefs are among the factors that influence the psychological mechanisms

of student motivation. Another factor to consider is the anxiety about mathematics. Students who suffer from math anxiety tend to withdraw from courses with a strong math (including engineering) which, ultimately constrain their choice of future career.

Acknowledgments

This work is supported by FEDER Funds through the Operational Programme Competitiveness Factors – COMPETE, and National Funds through FCT - Foundation for Science and Technology under the Project: FCOMP-01-0124-FEDER-022674.

References

Bakar, K.A., Tarmazia, R.A., Mahyuddina, R., Eliasa, H., Luana, W.L., & Ayub, A.F.M. (2010). Relationships between university students' achievement motivation, attitude and academic performance in Malaysia. In *Procedia - Social and Behavioral Sciences*. 2(2), 4906-4910.

Bandura, A. (2008). A Teoria Social Cognitiva na Perspectiva da Agência. In *Teoria Social Cognitiva: conceitos básicos,* 69-96.

Homayouni, A. (2011). Personality Traits And Emotional Intelligence As Predictors Of Learning English And Math. *Procedia - Social and Behavioral Sciences*, 30, 839-843. doi:10.1016/j.sbspro.2011.10.163

Kargar, M. Tarmizi, & R.A. Bayat, S. (2010). Relationship between Mathematical Thinking, Mathematics Anxiety and Mathematics Attitudes among University Students. In *Procedia - Social and Behavioral Sciences*. 8, 537-542.

Koaler, O., Baumert, J., & Schnabel, K. (2001). Does interest matter? The relationship between academic interest and achievement in mathematics. In *Journal for Research in Mathematics Education*, 32(5), 448–470.

Meelissen, M., & Luyten, H. (2008). The Dutch gender gap in mathematics: Small for achievement, substantial for beliefs and attitudes. In *Studies in Educational Evaluation*, 34(2), 82-93. doi:10.1016/j.stueduc.2008.04.004

Moenikia, M. & Zahed-Babelan, A. (2010). A Study of Simple and Multiple Relations between Mathematics Attitude, Academic Motivation and Intelligence Quotient with Mathematics Achievement. In *Procedia Social and Behavioral Sciences* 2, 1537–1542.

Muir, T. (2009). Numeracy at Home : Involving Parents in Mathematics Education. *Primary Mathematics*.

Neves, L. (2002). *Um estudo sobre as relações entre a percepção e as expectativas dos professores dos alunos e o desempenho em matemática*. Faculdade de Educação/UNICAMP

Patterson, M., Perry, E., Decker, C., Eckert, R., Klaus, S., Wendling, L. & Papanastasiou, E. (2003). Factors associated with high school mathematics performance in the United States. In *Studies in Educational Evaluation,* 29, 91-108.

Rouyendegh, B.D. & Can, G.F. (2011). Selection of working area for industrial engineering students. In *Procedia Social and Behavioral Sciences,* 31, 15-19.

Silveira, W. (2007). *Criando ambientes matemáticos com planilhas eletrónicas.* Rio de Janeiro. Centro Federal de Educação tecnológica Celso Suckow da Fonseca- CEFET/RJ, MSc thesis.

Sirmaci, N. (2010). The relationship between the attitudes towards mathematics and learning styles. In *Procedia - Social and Behavioral Sciences,* 9, 644-648.

Suthar, V. Tarmizi, R. A. Midi, C. & Adam, M. B. (2010) Students' Beliefs on Mathematics and Achievement of University Students: Logistics Regression Analysis. In *Procedia - Social and Behavioral Sciences*, 8, 525-531.

Torisu, E. M. & Ferreira, A.C. (2009). A teoria social cognitiva e o ensino-aprendizagem da matemática: considerações sobre as crenças de autoeficácia matemática. In *Ciências & Cognição*, 14(3), 168-177.

Vitasari, P., Herawan, T., Wahab, M. N. A., Othman, A., & Sinnadurai, S. K. (2010). Exploring Mathematics Anxiety among Engineering students. In *Procedia - Social and Behavioral Sciences*, 8, 482-489. doi:10.1016/j.sbspro.2010.12.066

Walter, J. G. & Hart, J. (2009). Understanding the complexities of student motivations in mathematics learning. In *The Journal of Mathematical Behavior*, 2-3(28), 162-170.