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Predictors of performance in engineering mathematics

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Mathematics in university courses was identified as a main obstacle for engineering students in the beginning of their study. Since difficulties with mathematics could lead to a dropout, our research aims to analyse students' profiles referring to individual characteristics that allow identifying possible risks for students' achievement or success in the first year of study. As a first step to identify possibly risky profiles, we started to find possible predictors of students' performance. For this, we give a short overview of the research state and our derived research interest. We discuss theoretical constructs that are possibly crucial characteristics of students with respect to encountering mathematics as an obstacle. Further, we describe the method for measuring different variables of 182 engineering students. Finally, we present results referring to predictors of performance in engineering mathematics and discuss further steps of our research.

Keywords: Teaching and learning of specific topics in university mathematics, Mathematics for engineers, motivational variables, students' profiles, students' achievement.

INTRODUCTION

Besides the technical disciplines, mathematics is a crucial part of higher engineering education (SEFI, 2013). Especially in the first year, mathematics is usually taught without considering practical applications. In lectures and tutorials mathematical basics are provided for subsequent technical courses. However, engineering students “encounter epistemological/ cognitive, sociological/ cultural and didactical obstacles” (Gómez-Chacón et al., 2015, p. 2117) with mathematics struggling with the transition from school mathematics to university mathematics (Gueudet, 2008). Considering mathematical school skills, students show remarkable deficits at the beginning of their study (e.g. Knospe, 2012; Thomas et al., 2012). Empirical studies show the importance of cognitive variables, since school grades and domain-specific previous knowledge are identified as important predictors of academic achievement (e.g. Hailikari et al., 2008). Moreover, there is also some evidence that mathematics plays a crucial role when dropouts from engineering studies are regarded. Heublein (2014) stated the highest dropout rates for mathematics laden studies that were partly caused by a low motivation and partly by excessive demands in the first part of the studies. Also, an international review study mentioned mathematical competencies as part of reasons for dropping out at universities (Søgaard Larsen, 2013).

Apart from cognitive aspects, further individual characteristics are relevant in the context of learning and study success. The importance of these different aspects, e.g. socio-demographic, motivational, emotional and social aspects, are explained by different theoretical models (e.g. utilization of learning opportunities model: Schrader & Helmke, 2015; models of dropout: Heublein et al., 2010) and proved by empirical findings. The meta-analysis by Hattie (2009) summarizes the results of over 800 studies and provides an overview of factors influencing learning success in school. Moreover, there is evidence for the impact of self-efficacy beliefs (e.g. Fellenberg & Hannover, 2006), academic self-concept (e.g. Hattie, 2009) and interest (e.g. Schiefele et al., 1993a) on performance.

RESEARCH QUESTION

In view of the research state, empirical findings show insufficient mathematical skills, high dropout rates and difficulties with mathematics at the beginning of engineering study. Research concerning higher engineering education mostly deals with the improvement of mathematics teaching through developing and evaluating interventions (e.g. through integrating mathematical and technical disciplines: Rooch et al., 2013). According to the utilization of learning opportunities model, learning success does not only depend on the teaching offer but also on its utilization by students. Therefore, in this project engineering students should be explored in more detail, especially with respect to mathematics and individual characteristics. Moreover, the study of Fellenberg & Hannover (2006) gives hints that a domain-specific investigation is also empirically meaningful. Concerning the time frame, our project focuses on the first year of engineering study because the secondary-tertiary transition and dropout surveys indicate serious problems at the beginning of study. In particular, more students decide to abandon one's studies within the first two semesters (Heublein et al. 2010).

Empirical basis for the relevance of individual characteristics in learning processes exists. However, most of the studies were conducted in the context of school. Since the subject matter and learning environment changes with the transition from school to university, these results cannot be transferred immediately. In contrast, studies of higher education with a special view of mathematics are rather rare. In particular, most studies concentrate on single aspects and not on an overview of different impacting variables (e.g. Schiefele et al. 2003). Therefore, our project draws on previous findings to explore a multitude of impacts of individual characteristics in learning processes of higher education with the main aim of developing mathematics related profiles of engineering students. As a student's profile we understand the characteristic of different individual variables, e.g. performance, motivational variables like interest (Gómez-Chacón et al., 2015), or engagement (Rach & Heinze, 2013), and further the relationships among these variables. Students' profiles should allow identifying possible risks for study success in the first year of the study. The

identification of students' profiles is useful because it allows the development of goal-oriented and adequate support services for students who encounter difficulties.

Since insufficient motivation and excessive demands for achievement are primary reasons for dropping out, we focus on motivational and cognitive variables as a first step to developing students' profiles. Moreover, students leaving their course of study are difficult to access, so we focus on available data like students' performance and individual characteristics with respect to the following research question:

Which domain-specific predictors of study success or failure can be determined in the first year of engineering mathematics?

THEORETICAL CONSTRUCTS

As a main construct that impacts on students' achievement, we refer to the construct of learning motivation as an umbrella term for different motivational variables (Spinath, 2011). Firstly, we choose all of the motivational variables that are summarized by the term learning motivation in order to identify the crucial impacting factors. Furthermore, all of the constructs are connected to the subject matter, so they might play a crucial role in the transition from school to university mathematics, a situation characterised by a changing subject matter and learning environment.

A first and main part of motivation is an individual's goal orientation (Dweck, 1986). This dispositional variable involves individual's beliefs about appropriate goals as a trait referring to specific and, thus, context-related tasks (Elliot et al., 1999). A further dispositional and motivational variable is interest which is differentiated into three components: feeling-related valences, value-related valences and an intrinsic character. Interest could be understood as an individual's development of an appreciation for a specific subject like mathematics (Wild & Möller, 2009). This definition involves the necessity to regard interest context-specific. One aspect of the construct of interest, i.e. the feeling-related valences is also a part of the expectancy-value-theory of Wigfield and Eccles (1992). They derive an individual's motivation for doing a task from the individual's expectancy of the success on a specific task and the incentive value of this task. Besides the intrinsic value, which is similar to the feeling-related valences of interest, further variables, i.e. attainment value, utility value and costs are part of achievement-related values. The expectancy of a success referring to specific tasks could be understood as individuals' self-efficacy beliefs (Wigfield & Eccles, 1992) that are close to the construct of self-concept (Shavelson et al., 1982).

Learning strategies is a further umbrella term that includes variables which also could have an impact on students' achievement (Wild, 2005). Learning strategies include cognitive learning strategies like strategies for elaborating a specific issue, meta-cognitive strategies like planning or monitoring the process of learning, or strategies to use resources like a specific learning environment. Finally, although students' achievement or success is hardly to define (Heublein, 2014), it could be

understood as the achievement in exams referring to a specific subject like mathematics or to proceed in a field of study like engineering despite encountered difficulties.

METHODOLOGY

Sample

Our first research step involved 182 engineering students at the University of Kassel enrolled in a calculus course in the summer semester 2017. Among the participants were 158 men and 24 women. Most of them started their second semester (67 %), though a small group of beginners is integrated (14 %). In the beginning of the semester, students of the calculus course were given a questionnaire concerning sociodemographic factors and motivational orientation towards mathematics. To achieve a high response rate, the students had two weeks to answer the questionnaire and received additional points for their permission to the final exam that could be achieved by solving weekly exercises. Students were also assured of the anonymity of their responses.

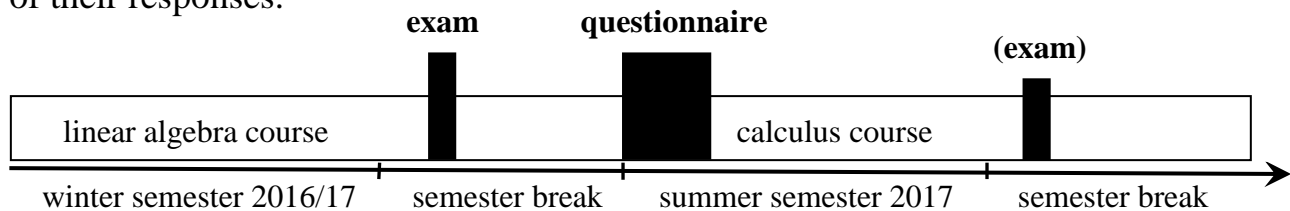


Figure 1: Time of data collection

Instruments

The so called SELLMO instrument (Spinath et al., 2012) was used to measure students' goal orientation towards mathematics. Twenty out of thirty-one items were chosen and especially referred to mathematics courses at university. Goal orientation is divided in four sub-scales with each five items concerning approaching and avoiding achievement goals, work avoidance and learning goals. One example for an item referring to learning goals is: "My aim for mathematics courses at university is to gain a deep understanding for the content."

For interest, we used a scale with nine items of Schiefele et al. (1993b) and adapted it to mathematics. One example for a negative formulated item of this scale is: "To be honest, I less care for mathematics." Referring to the expectancy-value-theory, we measured values with a scale involving six items that we developed according to Wigfield and Eccles (1992). One example for an item of this scale is: "Mathematical skills will be crucial for my future professional career." Further, we adapted each three items from the PISA study (Kunter et al., 2002) to measure students' self-concept and self-efficacy with respect to mathematics.

To measure the students' learning strategies, we focussed in the first step of our research on students' self-reports about the use of resources like lectures, tutorials

and special exercises. Whereas in lectures different mathematics topics are taught, students practice in tutorials by means of additional exercises. In the special exercises they discuss their homework and resolve open questions. Finally, students' success was measured by the self-reported grade in the final exam of the linear algebra course (see Fig. 1). By contrast, further grades of final exams in the abovementioned calculus course was directly given but is not analysed yet. Finally, we collected sociodemographic variables, e.g. the type of matriculation standard, according to a questionnaire used for dropout studies (Heublein et al., 2010).

RESULTS

Results in the first step of our research firstly refer to an evaluation of the instruments concerning the quality of scales. We further proved the predicting power of different variables on the students' performance measured by the self-reported grade in the final exam of the linear algebra course that students have taken the previous semester.

Evaluation of the instruments

In the first analyses, Cronbach's alpha estimates of reliability were determined for the scales from each instrument (see Tab. 1). Measures are adequately reliable, with values ranging from .552 to .844. Most of the values are appropriate, the lowest value (.552) was found for a scale with only three items.

Construct	Number of Items	Cronbach's Alpha
Mathematics Interest	9	.844
Goal orientation:		
Approach achievement goals	5	.722
Avoidance achievement goals	5	.827
Word avoidance	5	.727
Learning goals	5	.739
Expectancy-value-theory		
Mathematics self-concept	3	.704
Mathematics self-efficacy	3	.552
Value of mathematics	6	.690

Table 1: Sample constructs and Cronbach's Alphas

Possible predictors of performance in engineering: correlations

In each of the following analyses, we defined students' achievement as the self-reported exam grade of the linear algebra course that students have taken the previous semester. We firstly assessed the relationship between students' individual

characteristics referring to grades achieved in school. As seen in Table 2, the school grades and exam grades of the linear algebra course are significantly and positively correlated.

	Math school grade	Final school grade
exam grade	.321**	.393**

Table 2: Pearson's correlation coefficients between the exam grade and students' achievement in school (*p < 0.05; **p < 0.01)

We further proved the correlations between the exam grade and variables constituting the expectancy-value-theory. Except for interest, the correlations between the motivational variables and the students' achievement are significant. Particularly, there is a considerable relationship between the mathematics self-concept and the students' achievement.

	self-concept	self-efficacy	values	interest
exam grade	.554**	.363**	.385**	.166

Table 3: Pearson's correlation coefficients between the exam grade and students' individual characteristics (expectancy-value-theory)

By contrast, the correlations between the students' achievement and the students' individual characteristics referring to the construct of goal orientation are weak and except of the working avoidance, not significant.

	AAG1	AGG2	WA	LG
exam grade	.000	.177	.207*	.109

Table 4: Pearson's correlation coefficients between the exam grade and students' individual characteristics referring to AAG1 (Approach achievement goals), AAG2 (Avoidance achievement goals), WA (Work Avoidance), LG (Learning goals)

Using correlation analysis, we finally assessed the relationships between students' achievement and the students' engagement referring to external resources given by the attendance rate of lectures, tutorials and special exercises. However, the attendance rates seem to be independent of the students' achievement.

	Lecture	Tutorials	Special exercise
exam grade	.133	.074	.120

Table 5: Pearson's correlation coefficients between the exam grade and students' engagement

Possible predictors of performance in engineering: group comparison

To identify other possible predictors of the performance in engineering mathematics, we compared between distinct groups using t-tests. Firstly, we compared students that were enrolled in an advanced math course and students that were enrolled in usual math courses. Students in advanced math courses get more math lessons in a week and, thus, examine mathematics in a greater extent than students of usual math courses. As expected, students attending a math advanced course have significantly better grades in the exam of the linear algebra course (see Tab. 6). Further, we compared the group of students who were at a technical secondary school in which the extent of mathematics is lesser than in usual secondary schools. As expected, on average, students who had attended a technical secondary school obtained in the exam of the linear algebra course a grade of 4.0, whereas the corresponding grade for students who had not attended a technical secondary school was 3.5. Thus, students from a technical secondary school significantly perform worse in the linear algebra course than those who attended another type of school (see Tab. 6).

		Technical secondary school		Math advanced course	
		1	0	1	0
Exam grade	M	4.0	3,5	3.3	3.9
	SD	1,0	1,0	1,2	1,0
	Sig.	.016		.019	

Table 6: Exam grade of the linear algebra course depending on different subgroups (1 = attended; 0 = not attended)

DISCUSSION AND CONCLUSION

The development of engineering students' profiles referring to cognitive and motivational variables could potentially result in identifying students' risks for an undesirable low success or a dropout. For identifying possibly risky profiles, we started to find possible predictors of the students' achievement. Final school grades, maths self-beliefs, values of maths, the type of matriculation standard and the choice of advanced courses in school are meaningful predictors of performance in engineering mathematics. Hence, the results show that several variables determine the maths performance which should be considered seriously for the development of support services. However, the results reveal new questions leading to further possible research steps.

In conformity with the research state, the mathematical achievement as well as the amount of mathematics in school seem to be a predictor of the success in a final exam of the first semester. As a subsequent issue it is a crucial question if the impact of the former school time on the students' success in mathematics courses at

university decreases or disappears. Moreover, it is interesting whether previous knowledge measured by a skills test has a greater effect compared to the school grades. Perhaps, domain-specific skills can be recognised as special predictors of mathematics courses in engineering. In addition, the results show that the highest correlation exists between the final school grade and students' performance. This implies further influencing variables developed in the students' school time that impact on the students' achievement at university, especially learning activities and strategies. The fact that the attendance rates seem to be independent of the students' achievement strengthens this perspective.

Concerning the motivational variables, it is interesting that not all of them have an impact on the students' achievement. The students' mathematics self-concept that is also developed in the time of learning mathematics in school shows the highest correlation to the students' achievement. Therefore, support services should not only focus on the deficits in mathematics skills but also on the assistance of students' self-beliefs. Mathematics interest shows no impact on the mathematics performance. This result could approve findings like Eilerts (2009). Since engineering students do not choose mathematics voluntarily, mathematics interest might have no predicting power in this context. In this respect, it could be also interesting to differentiate in further analyses specific groups of students, e.g. concerning gender, the school form or other variables and to investigate if different groups show different relationships between motivational variables and the students' achievement.

Regarding the method, proven scales have been used and adapted to mathematics. Only scales with a low number of items can be extended to improve the reliability. All analyses base on simple correlations. Results can be improved and deepened by using further methods like regression analyses or structural equation models, so that an investigation of indirect effects is facilitated.

To conclude, in further steps of our research, the observation of motivational variables of engineering beginners should be continued and extended to the investigation of their development. Additionally, engineering students should be surveyed in respect of learning activities and strategies that we involved in this first study only by collecting data to the use of attendance rates (external resources). A detailed investigation of students' motives for non-attendance would give more information about engineering students' learning behaviour. Thus, building upon the first results of our research, we expect to deepen the desirable insight into students' profiles in the next steps of our research.

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