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CONCEPTIONS OF PRE-SERVICE ENGINEER EDUCATORS ABOUT THE ROLE OF MATHEMATICS AND THEIR APPROACHES TO STUDY

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Abstract: In this quantitative study, we investigate the relationship between the conceptions of first-year Engineering Education students about the role of mathematics in their studies and career, as well as the links of their conceptions with their approaches to study. The data analysis revealed that the students view mathematics as being about techniques, models and real-life applications and they conceptualise mathematics as being relevant to their future career and studies, though with a lack of knowledge of the specificities of this role. Nevertheless, the surface approach was correlated with a feeling of certainty with respect to the specific role of mathematics in their future studies and career, whilst the deep approach was found to be linked with a broad importance of mathematics. The implications of these complex findings are discussed.

Key words: Conceptions, Approaches to study, Engineer educators **MSC97C70, MSC97C20**

1. Introduction

The students experience mathematics in diverse ways and their experience effectively characterises the qualities of their learning mathematics. The students' conceptions at different levels of learning mathematics have been extensively researched (Di Martino, 2004; Leder, Pehkonen & Törner, 2003; McLeod, 1992). Mathematical education in educational environments where mathematics has a secondary and/or implicit role has recently been the focus of various research studies, including investigations about the attitudes and conceptions of the educational protagonists (Barkatsas, Kassimatis & Gialamas, 2009; Kassimati & Gialamas, 1998; Moutsios-Rentzos & Kalavasis, 2016), the affiliation of the learners (Bingolbali, Monaghan & Roper, 2007) and the role of the workplace (FitzSimons, 2001). Furthermore, research has suggested that the students' approach to study, their relatively consistent manner in which the students experience study has been linked with their educational outcomes (Biggs, 2003). Moreover, Crawford, Gordon, Nicholas & Prosser (1994, 1998), utilising a phenomenographic approach, investigated tertiary students' conceptions of mathematics and their approaches to learning mathematics. Their sample consisted of 300 students (first-year mathematics class) and they used open-ended questions. The results of their research indicated a correlation between students' conceptions of mathematics and their approach to learning. The findings revealed that students viewed mathematics in qualitatively different ways, contrasting *fragmented* with *cohesive* conceptions of mathematics. The students who displayed a cohesive conception of mathematics were more likely to use a deep approach, while the ones showing a fragmented conception were more likely to adopt a surface approach to learning.

In this study, we concentrate on the pre-service engineer educators of ASPETE (School of Pedagogical and Technological Education) in Greece. ASPETE presents particular research interest, since it aims at the promotion of applied research in educational technology and pedagogy, as well as at the specialization for prospective teachers. The mathematical education in ASPETE is connected with a particular subject of study (Electrical Engineers, Mechanical Engineers, Civil Engineers), which is related to mathematics and at the same time as pedagogical training on the specific subject of study. The content and structure of ASPETE's programmes reflect and support ASPETE's twofold

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orientation: the technological and the pedagogical. This interaction of pedagogical and technological education shapes a multidimensional educational environment, in which mathematical education is a challenge for all involved parties. Mathematical education in ASPETE is becoming even more complex, since around one out of four students who enter ASPETE are graduates of Vocational High Schools (EPAL) that present several differences and particularities when compared to General High Schools (GEL) in Greece (including, curricula, teaching practices etc.).

This heterogeneity –which includes the characteristics of the student population, the range and depth of the curricula, the different methods of delivery– underlines the need for further examination of the pre-service engineer educators' conceptions about mathematics and their approaches to study. Consequently, in the present study, we *focus on first-year ASPETE students, investigating*: *(1) their conceptions about mathematics, (2) their approaches to learning, and (3) the relationships between their conceptions about mathematics and their approaches to study.*

2. Conceptions about mathematics: focusing on engineers and engineer educators

Regarding the nature of mathematics, the conceptions about mathematics may be broadly categorized into the *absolutist perspective* that views mathematics as a fixed set of concepts (absolute knowledge, fixed and objective) and into the *fallibilist perspective* that considers mathematics as a social construct, the outcome of social processes, subject to revision and to different interpretations (Ernest, 1991). Daskologianni and Simpson (Daskalogianni & Simpson, 2001; Daskalogianni, in Moutsios-Rentzos, 2003) explored the beliefs of mathematics undergraduates to identify three categories (mathematics-related belief systems): *systematic* (mathematics is a static subject that consists of a rigid and fixed body of knowledge), *utilitarian* (mathematics is a science with direct applications in everyday life), and *exploratory* (mathematics related to problem solving, finding patterns, relationships and links). Moreover, researchers have studied conceptions of mathematics through the lenses of a systemic perspective (Beswick, 2006; Di Martino, 2004; Moutsios-Rentzos & Kalavasis, 2016; Liljedahl, 2008; Pehkonen & Pietilä, 2003; Törner, Rolka, Rösken & Sriraman; 2010).

Wood, Petocz and Reid (2012) explored the conceptions of undergraduate students of different departments and universities; initially through a qualitative approach (phenomenography) and subsequently through a quantitative approach (questionnaire), which in its final form consists of three parts: a) epistemological *conceptions of mathematics*, b) *mathematics in future studies*, and c) *mathematics in future career*. Their research aimed to show the qualitatively distinct ways in which students understand, experience, and ascribe meaning to mathematics. Considering conceptions of mathematics, their analysis identified three qualitatively distinct ways, in which students understand mathematics and a range of conceptions about it. The narrowest conception of mathematics indicated that '*mathematics is about numbers/components*' (individual and isolated components or techniques, including the notion of calculation). The broader conception of mathematics indicated that '*mathematics is about (abstract) models*' (models of real-world phenomena), while the broadest conception revealed the conception that '*mathematics is about life*' (an approach to life, a way of thinking and interpreting the world). Regarding the use of mathematics in future studies and career, they identified three subdimensions: a) *Practical*, focused on calculations, analysis, problem solving, and logical thinking, b) *Generic*, which includes a more general mathematical way of thinking and the recognition of the generic importance of mathematics in studies and careers), and c) *Knowledge (lack of)*, related to the knowledge or lack of knowledge of the specific role of mathematics in studies and in the career).

Specifically, with respect to the use of mathematics in the workplace, according to Fitzsimmons (2001) in most workplaces mathematical elements are included in specific workplace routines, structured by tools and equipment, specific templates, processes, record sheets etc. and are highly context-dependent. That means that the top priority is to do an effective job, rather than practice and apply mathematical skills. Fitzsimmons (2001) notes that school mathematics differ from practical mathematics, since current curricula barely reflect actual workplace practice, and recognises an urgent need to review and revise school and vocational education and the respective mathematics curricula, aiming at developing students' skills for work and other real-life situations.

In a research study with final year students in ASPETE, Moutsios-Rentzos and Kasimati (2014), adopted the research framework (theoretical and methodological) of Wood et al. (2012) and confirmed the intercultural reliability and validity of the research framework for the specific Greek population. In addition, the research findings revealed that the students' conceptions of mathematics were generally positive, as was the role of mathematics for their studies and future professional careers. However, positive conceptions seem generic and do not reveal in depth knowledge regarding the specific role of mathematics in future studies or in their career.

3. Approaches to study

There has been extensive research on students' learning in mathematics. A number of key theorists have revealed and described different dimensions, drawn from separate disciplines. Marton & Säljö (1976) introduced the notion of *approach to learning* and defined it as the specific manner in which students respond in experiencing or encountering a study situation. This approach has been generated to the known framework 'student approaches to learning' (Biggs, 1999; Dart & Boulton-Lewis, 1998; Entwistle & Waterston, 1988; Marton, 1981; Prosser & Trigwell, 1997). Marton and Säljö (1976) defined *surface approach* as the approach that some students use when they view the material as a mass of data that has to be memorised in order to answer the anticipated questions. On the contrary, a *deep approach* refers to the students treating the given material as something that contains a structure of meaning and has to be digested and understood ('knowledge-making'). Their study revealed that the students who were adopting deep approach to study tended to have higher quality learning outcomes. Biggs (1976), following a different line of research, identified a similar qualitative distinction. According to Biggs (1976), the deep approach is related to focusing on the meaning and on the ideas contained in a task, including engagement in meaningful learning and interaction with the learning material in seeking personal understanding. He claims that the deep approach derives from the intrinsic desires of students to learn: "When students feel this need-to-know, they automatically try to focus on underlying meanings, on main ideas, themes, principles or successful applications" (Biggs & Tang, 2007, p. 24). On the contrary, the surface approach suggests that the students study the material in a superficial manner, with little use of meta-cognitive skills and refers to dealing with surface elements in the learning processes. Nevertheless, Biggs (1976) identified an additional third approach: the *achieving approach*, which emphasizes the need for achievement and demonstrates the explicit link of the approach with the specific assessment demands and the accomplishment of the highest possible grades.

Biggs (2003) suggested that a student's approach to learning depends on the way that the student approaches the task (strategy) and the reason that the student wants to approach it (motive). That means that he associates the type of motivation with the adoption of a specific learning strategy. More specifically, the surface approach, according to Biggs (2003) derives from the student's extrinsic motivation to avoid failure and complete the assigned learning tasks, while the achieving approach derives from a strategic motivation and is targeted to the obtainment of high grades. As far as the deep approach is concerned, Biggs suggests that the students who adopt such an approach are intrinsically motivated and make use of strategies that promote conceptual understanding. Hence there is not enough evidence to support that intrinsic motivation always results to academic success.

Biggs (1976) adopted an information processing perspective to develop his Study Process Questionnaire (SPQ), in parallels with Marton and Säljö (1976) who followed a phenomenographic approach, and with Entwistle (Entwistle, Hanley & Hounsell, 1979), who developed his research from the perspective of the psychology of individual differences. SPQ measures students' approaches to learning as schematised in the *Presage-Process-Product* (3P). The SPQ, and the revised version of SPQ (Biggs, Kember & Leung, 2001), were based on Biggs's (1987) *3P model* (Presage-Process-Product), of student learning. This specific model portrays three elements that influence the result of learning and examines, how student factors interacting with the teaching and learning process affect the learning outcomes' attainment. *Presage* refers to pre-existing variables, including characteristics of the learning context and of the students. These characteristics interact at the process level in order to determine the student's choice of approach to learning. Students' study approaches are affected by their personality, prior personal, social and educational background and experiences, include their

expectations and values and reflect a repertoire of discursive practices of various social groups (student-dependent factors). There are also factors that depend on the teaching context that might increase the likelihood of the adoption of the surface approach to learning, including: the course objectives, the assessment procedures (for example, when they aim mainly at memorising rather understanding), the teaching methods (for example, when providing inadequate time) and others. *Process* refers to the ways that students and teachers approach the given tasks (surface/deep learning and teacher-centred/student-centred teaching). This phase involves the activities that students undertake and depends on their reflection (meta-learning, conscious awareness over one's own learning); that is, on how they perceive themselves, the task and the context. *Product* refers to the learning outcomes, which may be quantitative, qualitative and affective. According to Biggs (2003), student and teaching dependent factors determine the specific approach that a student will use on a given task, which subsequently determines the result. Thus, approaches to learning are the result of the constant interaction between the students' learner characteristics and the specific learning environment, reflected in students' academic outcomes.

4. Methods and procedures

The study was conducted with first-year students of ASPETE in January 2016, after the completion of the autumn semester. The exclusion criterion from the study was the presence of less than eight (of the 13) weeks of teaching, in order to ensure adequate experience with mathematics both as content and as a teaching practice in ASPETE. A total of 107 students (N = 107) participated in the survey (see Table 1). Please note that admission to ASPETE is possible through the procedures specified by the educational system of Greece, which entails examinations in a national level held in the last year of High School. The two main types of the three-year High School existing in the Greek educational System are the General High Schools (GEL), which are academically oriented high schools and Vocational High Schools (EPAL), which provide technical and vocational courses.

Table 1. *The participants of this study (N=107).*

			f	valid%
Gender	Male		79	73.8
	Female		28	26.2
Admission	Vocational high school		30	28.0
	General high school		77	72.0
		Technological	67	62.6
		Scientific	8	7.5
		Theoretical	2	1.9
Parents' studies	Father	Primary	12	11.4
		Junior High	16	15.2
		Senior High	37	35.2
		Technological University	27	25.7
		University	13	12.4
	Mother	Primary	11	10.5
		Junior High	6	5.7
		Senior High	58	55.2
		Technological University	18	17.1
		University	12	11.4

Considering data collection, in the present study, we adopt the methodological framework and the questionnaire of Wood et al. (2012) as employed by Moutsios-Rentzos and Kassimati in Greek (2014), as well as the differentiation in deep-surface approaches as identified by Revised Two-Factor Study Process Questionnaire (R-SPQ-2F; Biggs et al., 2001). Regarding conceptions of mathematics, in this study, we adopt the questionnaire proposed by Wood et al. (2012), as utilised in Moutsios-Rentzos and Kassimati (2014). The first section of the Questionnaire of Wood et al (2012) aims to explore the students' epistemological conceptions of Mathematics (16 items) that are divided into three main axes: Numbers / Components, Modelling / Abstract and Life. The second part of the questionnaire focuses on the Future Use of Mathematics in Studies (14 items), while the third section explores the Future

Use of Mathematics in Career (16 items). In line with the theoretical background of the questionnaire, three scales are recognized: 'Practical', 'Generic', and 'Knowledge' (lack of). The items are Likert type (5-level scale) allowing the perceptions to be recorded independently for each axis and each scale of the questionnaire. Moutsios-Rentzos and Kassimati (2014) reported that structure of the three parts of the translated questionnaire is in semantic agreement with the original by enhancing its validity. The internal consistency of the three axes and the six scales of the translated questionnaire is judged to be satisfactory with an average $\alpha = 0.812 \pm 0.06$ [0.698-0.870]. Thus, the questionnaire may be utilised for the purposes of the present study.

With respect to approaches to study, the SPQ (Study Process Questionnaire) questionnaire was used to measure approaches to learning (see Biggs 2001). A more recent and shorter version explores two of the three study approaches (deep and surface approaches) in a valid and reliable way (R-SPQ-2F; Biggs, Kember & Leung, 2001). The questionnaire consists of 20 questions regarding students' attitudes towards their studies and their usual way of studying. The questionnaire investigates the two learning approaches: the deep approach (deep motive and deep strategy) and the surface approach (surface motive and surface strategy). The students were asked to express their approaches to learning using a 5-point Likert-type scale. It is stressed that in his most recent research study, Biggs et al (2001) suggest that the approaches should be interpreted as representations of student interaction in the university environment, rather than as a characteristic that goes beyond the educational framework. In this respect, study approaches are a tool for investigating the effectiveness of the teaching process in a given educational context. The latent structure of the translated to Greek R-SPQ-2F (as revealed by Principal Axis Factoring) matches perfectly the original version, whilst the internal consistency of the two scales was found to be $\alpha_{Deep} = 0.798$ and $\alpha_{Surface} = 0.786$. Consequently, the translated to Greek R-SPQ-2F showed sufficiently good psychometrics to be used for the purposes of this study.

The descriptive and non-parametric inferential analyses were conducted with the SPSS 23, including One-sample Wilcoxon signed rank tests and Kendall's tau correlations.

5. Results

5.1 The students' conceptions about mathematics and their approaches to study

The students reported conceptions to be statistically significantly higher than the theoretical neutral (see Table 2). In specific, they view mathematics to be statistically significantly more about Number/Components, Modelling/Abstract and Life. With respect to their future studies and their future career, the students seem to statistically significantly acknowledge its practical and generic role. Nevertheless, this acknowledgement is combined with a statistically significant higher lack of knowledge of the specific role that mathematics would play in their studies and career.

Table 2. *The participants' conceptions about mathematics*.

		Mean	*Median*	*P* [a]
Conceptions	Number/Components	3.5	3.7	<0.001
	Modelling/Abstract	4.0	4.0	<0.001
	Life	3.3	3.2	<0.001
Studies	Practical	4.0	4.0	<0.001
	Generic	3.6	3.5	<0.001
	Knowledge	3.8	4.0	<0.001
Career	Practical	3.8	3.8	<0.001
	Generic	3.4	3.3	<0.001
	Knowledge	3.4	3.4	<0.001
[a]: One-sample Wilcoxon signed rank test to the hypothesised median "3": "Neutral/I don't know".				

Considering the students' approaches, the findings of the analysis revealed that the students report a statistically significantly lower than the theoretical neutral surface approach. Nevertheless, this is combined with their reporting not to be statistically significantly different than the theoretical neutral with respect to the deep approach.

Table 3. *The students' approaches to study.*

	Mean	*Median*	*P* [a]
Deep Approach	3.0	3.0	0.686
Surface Approach	2.4	2.4	<0.001

[a]: One-sample Wilcoxon signed rank test to the hypothesised median "3": "this item is true of me about half the time".

5.2 Linking the students' approaches and conceptions

The following analyses aimed to reveal statistically significant relationships (correlations) amongst the students' approaches to study and their conceptions about mathematics (see Table 4). The findings of the analyses revealed that the deep approach was statistically significantly positively correlated with their conceptions of mathematics as being Modelling/Abstract and Life. In contrast, no statistically significant correlations were found between the epistemological conceptions and the surface approach. Considering the role of mathematics in their future studies and career, the deep approach was found to be statistically significantly positively correlated with a generic conception, whist it was also found to be statistically significantly positively correlated with a practical conception with respect only the career. In contrast, the surface approach was found only to be statistically significantly negatively correlated with the lack of knowledge of the specific role of mathematics in their studies and career.

Table 4. *Correlations amongst conceptions about mathematics and approaches to study.*

Conceptions			*Approaches to study*	
			Deep	Surface
Mathematics	Number/Components	τ [a]	0.102	0.062
		P [a]	0.145	0.370
	Modelling/Abstract	τ	0.142	-0.058
		P	0.046	0.415
	Life	τ	0.212	0.016
		P	0.002	0.817
Studies	Practical	τ	0.113	0.084
		P	0.108	0.232
	Generic	τ	0.222	0.025
		P	0.001	0.717
	Knowledge	τ	0.053	-0.256
		P	0.457	<0.001
Career	Practical	τ	0.154	-0.116
		P	0.031	0.102
	Generic	τ	0.241	-0.009
		P	0.001	0.901
	Knowledge	τ	0.114	-0.238
		P	0.102	0.001

[a]: Kendall's tau non-parametric correlation.

6. Discussion and concluding remarks

The overarching aim of this study was to investigate ASPETE's first year students' conceptions about mathematics, their approaches to learning, and the relationships amongst their conceptions and their approaches to study. The research findings revealed the students' higher epistemological conceptions about mathematics as being Numbers/Elements, Modelling/Abstract and Life). This is in accordance with the research study of Wood et al. (2012), since the students that exhibited narrower conceptions were hesitant to identify and describe specific characteristics of mathematics, while the ones who were able to discuss characteristics and demonstrate their understanding, exhibited more expansive views of mathematics.

Regarding the approaches to study, although the students exhibit a lower surface approach from the theoretical neutral, they do not demonstrate a respective increased deep approach. On the one hand, the lower surface approach seems reasonable, since these students are those who successfully survived

a national exams filtering system, thus with higher academic performance, which in the literature has been found to be linked with higher deep approach and/or lower surface approach (Biggs, 2003). Nevertheless, the fact that the deep approach has not been found to statistically significantly differ from the neutral, may be linked with the fact that these students come from an educational system that, in reality, devotes the last two years of senior high-school solely for their preparation for the entering university examinations. A system that seems not to promote critical thinking and to favour the students' capacity for memorisation of an enormous quantity of data, in order to obtain the necessary marks to enter university. In the current filtering examination system, the high school students that are not capable of memorising and reproducing their school books, seem to be stand little chance of good grades at the national level examinations. Thus, it is reasonable for the successful students of this system not to report having a higher deep approach.

Furthermore, the findings of the present study reveal a statistically significant positive correlation between a deep approach to learning and specific epistemological conceptions of the students about mathematics: as being Modelling/Abstract and Life (but not with Number/Components). This implies that the students who employ a deeper approach to study, identify more that mathematics is models of real-world phenomena, translating some aspect of reality into mathematical form, and/or that mathematics is about life, a way of interpreting the world, a set of thinking. Nevertheless, their having a deeper approach does not imply their viewing mathematics as being more about individual and isolated components or techniques. Consequently, it may be inferred that the students who develop higher deep approach to their studying construct an epistemic view of mathematics as being more about abstract models of real-life situations, built upon a relatively to their approaches fixed core of set of rules and techniques (though statistically significantly higher than the theoretical neutral). In stark contrast, the surface approach seems not to be linked with the students' formation and development of epistemic views. It is interesting to pursuit these results as the students' progress through their studies in ASPETE, to investigate the development of these links (cf. Moutsios-Rentzos & Simpson, 2010).

Regarding the students' conceptions of the role of mathematics in their future, the findings revealed that although they are positive, they are of general character and are linked with a lack of the specific knowledge of the role that mathematics would play in their studies and career. This is especially important, as these students are future engineer educators and mathematics is an important part of their studies and their career. Furthermore, this result does not accord with the findings of Wood et al. (2012), who found the engineering students to have similar conceptions as mathematics majors. A notable finding is that only students who adopt the deep approach identified a practical role for mathematics in their future career (though not in their future studies). According to Candy, Crebert and O'Leary (1994) one of the main purposes of undergraduate education is to cultivate students' lifelong learning attitudes and develop their skills, in order to guide them towards deeper approaches to study and learning, although learning approaches are also influenced by factors found beyond the learning context. FitzSimmons (2001) underlines that the existing curricula barely reflect actual workplace practices, identifying the need to change mathematics education and mathematics curricula, aiming at improving students' work skill, as well as in other real-life situations.

We assume that these complex conceptions may also be related to the multifaceted, multidimensional, pedagogical and technological, student experience in ASPETE, as well as to the particular identity formed during the course of study. Given the above findings, we suggest that there is a need to design and develop broader research studies to further explore the impact of studies in ASPETE, either by a longitudinal research (comparing first-year graduates) or by a longitudinal study (from the first year to the graduation) that could increase our understanding and yield important insights regarding the formation process of these concepts. For the same purpose, a comparative study of the students of the respective Higher Technological Education Institutes (ATEIs) could help to situate the aspects of these findings linked with studying in ASPETE. In conclusion, the findings of the present study revealed that the prospective engineering educators who enter university share a complex spectrum of conceptions about mathematics, which are linked with a deep approach to study. Our current research project draws upon these findings to obtain a mapping of the development of these relationships as the students' progress through their studies, with the purpose to inform the teaching practices towards a more effective and meaningful for these students mathematics education.

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