

Effective mathematics teaching in tertiary technological education: The case of ASPETE

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Abstract

In this mixed methods study, we draw upon a systemic perspective to investigate the way that effective mathematics teaching is constructed in the ASPETE (School of Pedagogical and Technological Education) learning system. We focused on the perspectives of the first-year students (through questionnaires), of the lecturer who taught the course (through interviews), as well as of the research team (through observations). We considered both the pragmatic level (what they actually experienced) and the desired level (what they would prefer to experience). The results of the conducted analyses support the proposed research approach, revealing convergences and divergences in the mapped perspectives, which identify the mathematics teaching effectiveness of the subsystem of the mathematics class in ASPETE as an emergent, systemic phenomenon. The pedagogical implications are discussed, with respect to the planifications of teaching and learning mathematics in the ASPETE learning system.

Keywords: System, teaching effectiveness, mathematics education, conceptions, technological education.

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1. Introduction

Over the decades, many issues have emerged regarding the definition, the measurement and the evaluation of mathematics teachers' effectiveness. Effective teaching and learning are very complex and multifaceted, and therefore attempting to define them can be a challenging and controversial process. Mathematics is at the crux of modern sciences, as, on the one hand, mathematics constitutes the language of communicating and validating scientific results, and, on the other hand, mathematics is linked to the way societal structures are established and communicated (including health, economy, insurance policies and, in general, policies and rules of social governance).

Considering mathematics education, the students experience mathematics teaching in different manners, which affects the ways they conceptualise mathematics and the quality of the mathematics they learn. There has been extensive research regarding the conceptions of students at various levels of learning mathematics (Di Martino, 2004; McLeod, 1992) that have had implications for both educational practice and research. A plethora of recent research studies have focused on the attitudes and conceptions regarding the different protagonists of the mathematics educational process (Barkatsas, Kassimatis & Gialamas, 2009; Beswick, 2012; Crawford, Gordon, Nicholas & Prosser, 1994; 1998; Maab & Schloglmann, 2008; Moutsios-Rentzos & Kalavasis, 2016), the affiliation of trainees (Bingolbali, Monaghan & Roper, 2007) and the role of the workplace (FitzSimons, 2001; 2013; Maass & Engeln, 2019).

In this study, we focus on ASPETE and the effectiveness of mathematics teaching in this institute. ASPETE is a Greek tertiary education institute that incorporates a unique educational complexity, as its graduates hold an engineering degree (Electrical Engineers, Mechanical Engineers or Civil Engineers) and a pedagogical degree as an engineering educator (who may teach in vocational high schools in Greece). Thus, ASPETE's programmes include a twofold orientation: technological and pedagogical. This combination of pedagogical and technological education creates a dynamic educational environment, in which effective mathematical education is a big challenge for all involved parties (cf., Pohjolainen, Myllykoski, Mercat & Sosnovsky, 2018). Moreover, the students of ASPETE have diverse pre-ASPETE mathematics experiences. One out of four attended vocational high schools, thus having different mathematical experiences with respect to the teaching and learning phenomena (for example, teaching practices, curricula, etc.), when compared to the students who attended the 'general' high school ('Lykeio'). This heterogeneity of the student population, the great variety and depth of curricula, as well as the different educational methods underline the need to investigate the teaching and learning phenomena in ASPETE. In previous studies, we focussed on the pre-service engineer educators' conceptions about mathematics, also linked to the approaches to study (Kasimatis, Moutsios-Rentzos, Rozou & Matzakos, 2018; Moutsios-Rentzos & Kasimati, 2014). In this study, we built upon these projects to further investigate mathematics teaching and learning in ASPETE, with a particular focus on effective mathematics teaching following a systemic approach.

We adopted a systemic perspective (Moutsios-Rentzos & Kalavasis, 2016) to investigate the effectiveness of mathematics teaching, with respect to the ASPETE system and the complexity it entails. In particular, we focused on the subsystem of the mathematics class of a department in ASPETE and we conceptualised effective mathematics teaching to emerge among the complex interactions of educational protagonists (in this study, the lecturer and the students), with the purpose to investigate the potentially diverse intentionalities that co-exist in the everyday mathematics class in ASPETE. Consequently, in this study, we investigate the effectiveness of mathematics teaching as an emergent, systemic phenomenon.

2. Conceptualising mathematics teaching effectiveness in the ASPETE learning system

Various research projects investigating the teachers' effectiveness have focused, on the one hand, on the classroom level without linking it to wider factors, whereas, on the other hand, studies have

employed a macroscopic perspective including broader educational phenomena with little emphasis on specific teaching practices and behaviours. In this article, we report an aspect of an on-going broader research programme that investigates the teaching of mathematics in ASPETE (Mathematics Education and Technological Education; MATHETE). We draw upon a systemic perspective (Begg, 2003; Chen & Stroup, 1993; Davis & Simmt, 2003; Davis & Sumara, 2005; English, 2007, 2008; Kalavasis, Kafoussi, Skoumpourdi & Tatsis, 2010; Moutsios-Rentzos, da Costa, Prado & Kalavasis, 2015b; Pepin & Roesken-Winter, 2014; Thornton, Shepperson & Canavero, 2007; Wittmann, 2001, 2005) with the purpose to link the macro-level of the educational unit to the micro-level of the in-call teaching of a specific course: mathematics.

A system is defined as a whole, the parts of which are linked and interrelated in such complex ways towards specific goals that the constructed whole significantly differs from a simple adding of its parts (Bertalanffy, 1968; Moutsios-Rentzos & Kalavasis, 2016). Hence, ASPETE may be viewed as an open learning system, consisting of subsystems (such as the various departments and sections; cf. Cobb & Jackson, 2008) that interact with each other. At the same time, elements of the system and the subsystems form complex relationships. Furthermore, the ASPETE system constitutes a subsystem of a broader interacting educational and social system (including the students' family system; Kalavasis & Kazadi, 2015; Moutsios-Rentzos, Chaviaris & Kafoussi, 2015a). Following these, the various educational protagonists (lecturers, students, head of the department, etc.) may assume diverse roles within the system. For example, a student's parent may also be a lecturer and/or the head of a department.

Regarding teaching effectiveness, several studies have been conducted employing diverse models (Bardach & Klassen, 2020; Creemers & Kyriakides, 2008; McCroskey & Richmond, 1990; Muijs & Reynolds, 2017). For the purposes of this study, we chose the model of teaching effectiveness conceptualised by Patrick and Smart (1998) because it is a model that builds on the students' evaluations, it is explicitly concentrated on higher educational institutes and it synthesises the core dimensions of other models, resulting in only three factors. Moreover, we chose this general model of teaching effectiveness, rather than a mathematics teaching effectiveness-focussed model (Backes, Goldhaber, Cade, Sullivan & Dodson, 2018; Cai, Kaiser, Perry & Wong, 2009; Swars, 2005), in order to allow for aspects of mathematics teaching effectiveness that may be specific to our population of interest to be visible and, importantly for this study, to be in line with the systemic approach to mathematics teaching effectiveness.

Patrick and Smart (1998) aimed to examine and measure the nature, as well as the dimensions, of teaching effectiveness. The research was carried out in two distinct phases with undergraduate students. In the first phase, the students were asked to identify positive teacher qualities, while in phase two the items from existing instruments were combined to measure effective teaching with items produced in phase one. The result of this process was an instrument that conceptualised the effectiveness of teachers as being multidimensional, which accorded well with the existing research results. In particular, according to Patrick and Smart (1998), the effectiveness of the teacher consists of three factors: 'respect for students, ability to challenge students, and organisation and presentation skills'.

In this study, we drew upon Moutsios-Rentzos and Kalavasis's (2016) work to include in our investigations the mathematics teaching effectiveness of both the educational protagonists in the in-classroom interaction: the students and the lecturer. Moutsios-Rentzos and Kalavasis (2016, p. 105–106) proposed an inter-systemic, multi-focussed approach to investigate the mathematics teaching and learning phenomena within the educational unit. They 'consider mathematics within the system of disciplines, essentially altering the focal point in order to identify epistemic views about mathematics in relation with the other disciplines'. Moreover, they consider the educational unit 'from three interacting and interrelated perspectives that each protagonist assumes: a) the *symbolic/normative* (the perceived official regulations), b) the *pragmatic representations* (the

perceived current state of school practices), and c) the *desired/intentioned actions* (the personal hypothetical actions, assuming the power to implement them)'.

For the purposes of this project, we focussed on two of the three levels of in-classroom interaction: the pragmatic level and the desired/intentioned level. Thus, for the students and the lecturer, we mapped the reality they experienced, as well as the reality they would prefer to experience. Furthermore, we included a view from the environment of the mathematics class subsystem and the ASPETE system in general: the researcher's observation. The latter is considered particularly important, as when comparing the views of the lecturer with those of the students, we obtain a measure of convergences and divergences between the two mappings, while the perspective of the researcher provides a measure of the position of the two mappings in the broader space of the system. Consequently, in our approach, we attempt to map the mathematics teaching effectiveness for the class system, rather than only for some of the protagonists. For this purpose, we included the view of the researcher, as another means for mapping the system, which, in our approach, is also included in the system.

Following these, we conceptualise mathematics teaching effectiveness as an emerging phenomenon, stemming from and beyond the different realities that the educational protagonists experience. In particular, we concentrate on the way effective mathematics teaching is constructed in the ASPETE mathematics class system: a) as conceptualised by the first-year students, b) as conceptualised by the lecturer who taught the course, and c) as observed by a member of our research team. Our tri-faceted approach is synthesised with the two levels of reality (pragmatic and desired/intentioned), in order to obtain a map of the lived reality that includes both the present and the desired/intentioned future. In Figure 1, we draw upon Moutsios-Rentzos and Kalavasis's (2016) work to diagrammatically outline our perspective.

3. Methodology: a systemic approach to mathematics teaching effectiveness

3.1. Mapping the students' perspective

Considering the identification of the students' conceptions about the effectiveness of their mathematics lecturer, for the purposes of this study, we modified the instrument of Patrick and Smart (1998). We asked the students to reflect upon the actual teaching of the course Mathematics I, as well as upon their desired teaching reality. We drew upon the questionnaire of Patrick and Smart (1998) and we differentiated the pragmatic from the desired level on the answering scheme of each item. Figure 2 shows a sample item from the questionnaire employed. Note that the item is the same as in Patrick and Smart's (1998) questionnaire, but the students were asked to provide two answers: one referring to their experience of what they thought actually happened during teaching and one investigating what they would like to happen during teaching. Overall, the three factors of Patrick and Smart's model were identified through 24 dyads of 5-point Likert type items (Figure 2). The statistical analyses were conducted with *Statistical Package for the Social Sciences 25*. They included descriptive statistics and the one-sample Wilcoxon Signed test, in order to investigate a statistically significant deviation from the conceptually neutral Likert scale (in this case, denoted by '3').

3.2. Mapping the lecturers' perspective

Regarding the lecturer's conceptions, a two-hour, semi-structured interview (designed to follow the content of the students' questionnaire) was conducted. The semi-structured interview was chosen since it is a method that offers a two-way communication with the participants and permits the interviewer to explore conceptions in more depth (Arksey & Knight, 1999). For the purpose of this specific study, reflection was considered as the lecturer's interpretation of her teaching strategy and practices. The audio-recorded, semi-structured interview was conducted with the use of a set of open-ended questions, which was expected to allow the interviewee the freedom to express her views in

her own terms, while encouraging communication with the interviewer. The content of the interview questions was in line with the content of the students' questionnaire. Nevertheless, questions were also asked with respect to the symbolic/normative level. The interview was transcribed, and a thematic analysis was conducted with the transcriptions.

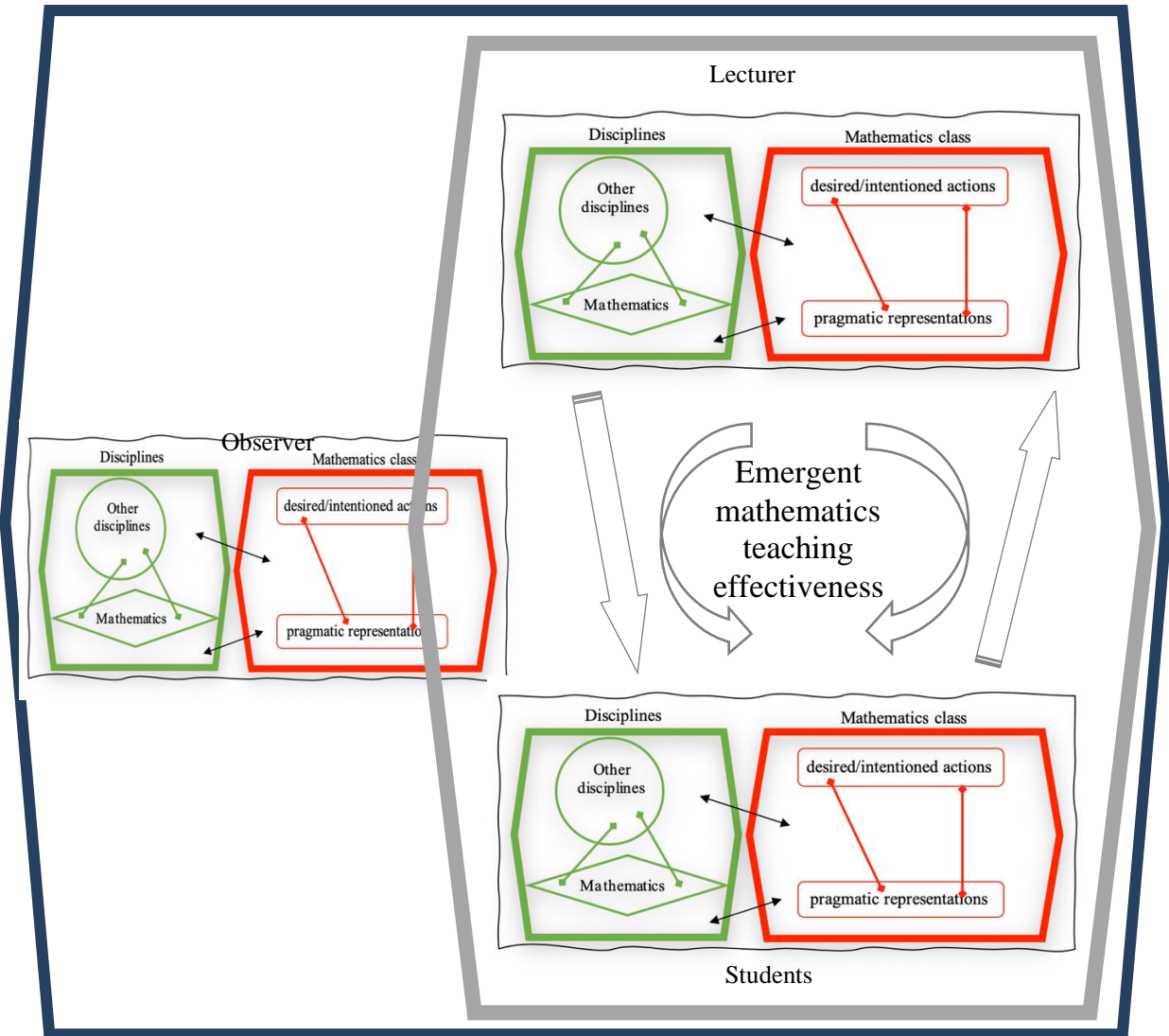


Figure 1. The systemic approach to mathematics teaching effectiveness as conceptualised in this study (drawing upon Moutsios-Rentzos & Kalavasis, 2016)

	During teaching it happened ...					I would like it to happen ...				
	almost never	rarely	sometimes	often	almost always	considerably less frequently	less frequently	as frequently as it did	More frequently	much more frequently
According to your experience of the teaching of the course Mathematics I in this semester, the lecturer ...										
1. Treated you as equal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 2. Sample item of the questionnaire employed in the study (adapted from Patrick & Smart, 1998)

3.3. The researchers' perspective

Considering the researcher's perspective, direct, structured classroom observations were conducted during the whole semester. Overall, 10 direct, three-hour-long observations were conducted. The number of students attending ranged from 40 to 60 (in Greece, in many courses attendance is not obligatory). The teacher informed the students that the session would be observed, and the observer was introduced to the class. The observer did not interrupt the flow of the class, listing the on-going activities according to an observation scheme (including teaching methods and techniques, communicational techniques, etc.). The collected research material was analysed and coded into thematic categories.

4. Results: the emergent map of the effective mathematics teacher in ASPETE

4.1. The students' perspective

The students' conceptions about mathematics teaching effectiveness are summarised in Table 1. Considering the pragmatic level, the students seemed to be statistically significantly satisfied by the teacher's effectiveness on all the dimensions of the measured effectiveness (respect, organisation and challenge). At the same time, they expressed a statistically significant desire for further improvement in all dimensions of the teaching effectiveness. Nevertheless, it should be stressed that their satisfaction noematically corresponds to 'often', whereas their desire is closer to 'as frequently as it did'. We argue that this implies that the students considered this lecturer to be effective in all the measured dimensions and that they identify a marginal (yet statistically significant) area of improvement.

Table 1. Mathematics teaching effectiveness as conceptualised by the students

Effectiveness	Reality levels	<i>M</i>	<i>Mdn</i>	<i>Pa</i>
Respect	Pragmatic ^b	4.1	4.3	<0.001
	Desired/Intentioned ^c	3.3	3.0	<0.001
Organisation	Pragmatic	4.2	4.4	<0.001
	Desired/Intentioned	3.3	3.0	<0.001
Challenge	Pragmatic	3.9	3.9	<0.001
	Desired/Intentioned	3.3	3.0	<0.001

^aOne-sample Wilcoxon Signed test, to investigate statistically significant deviation from the conceptually neutral '3'.

^b'1': almost never, '2': rarely, '3': sometimes, '4': often. '5': almost always.

^c'1': considerably less frequently, '2': less frequently, '3': as frequently as it did, '4': more frequently. '5': much more frequently.

4.2. The lecturer's perspective

The lecturer's interview revealed the complex lived reality that she experiences, as she critically reflected upon her teaching experiences of the particular semester, referring at the same time to her past lecturing experiences and to her intentions and thoughts of future teaching practices. The results of the thematic analysis revealed that her answers could be organised in the following themes: 'about mathematics and her role as a teacher; about her teaching as it happened; and about her teaching as she would like it to happen in the future'.

Regarding mathematics and her role as a teacher she suggested: 'Mathematics are actually the base for all other subjects' and 'Mathematics help students to develop a specific way of thinking. They learn to think outside the box – a valuable ability in today's world and their profession'. Furthermore, she

commented about her role: 'I think my role was to build an enabling environment, to motivate my students, to guide and support them'.

About her teaching as it happened, the teacher suggested: 'I tried to reflect on the mission, values and specialisation of the institution and connect Mathematics through specific examples with the specialisation of my students'. She stressed: 'I tried to design and teach this course in a way that fosters all students, but especially the less developed students', and proposed: 'We must adapt to the students' level, which is not very high'. Moreover, she referred to her teaching practice, highlighting that: 'I tried to keep my instruction practical and useful, not theoretical, and used a lot of examples', 'I used scaffolding as a teaching strategy and asked open questions, so that each student becomes part of the conversation, and member of the learning community'.

Considering her teaching as she would like it to happen in the future, she underlined: 'Since it is the first time that I taught in ASPETE, if I had to teach this class again, I would re-consider my students' needs and make changes accordingly'. Furthermore, she added: 'Reflecting on my practice some changes in my classroom practice and more attention to students' difficulties, maybe connect more the given examples to their specialisation. Moreover, I could make more use of e-class'.

4.3. The researcher's observations

The qualitative analyses of the observed teaching practices revealed four themes: 'well designed and coherent lessons; use of different instructional techniques; communicative approach; and student centredness, student engagement and students' motivation'.

Our observations accorded with the students' pragmatic conceptions, as we identified well-designed and coherent lessons. The teacher exhibited instructional coherence. Each part of the lesson was designed to contribute to a conceptual whole, supporting the students' meaningful linkings. The observations also showed content-focused and goal-oriented lessons. We noted clear instructions and clearly set expectations, while the students were offered opportunities to recall and use prior knowledge.

Moreover, we noted the use of different instructional techniques. The lecturer used differentiated instructions when needed. She employed various representations to communicate mathematical ideas (e.g. by drawing tables and diagrams on the board). In addition, her teaching included whole-class discussions and working in pairs.

Considering the lecturer's attempt to employ a communicative approach, she used key questions and examples in order to communicate to the students' the key ideas in a meaningful manner.

Regarding student centredness and student engagement, the lecturer attempted to engage students as partners in the instructional process and to integrate students' voices into the classroom community, encouraging the whole class in sharing ideas and solutions. The observations revealed her being encouraging and promoting of motivation, attempting to connect mathematics to other disciplines. Nevertheless, we noted that although the majority of the class seemed to be engaged in the activities, less than half of the students actively participated in the whole group discussions.

5. Discussion

It is posited that the employed theoretical and methodological approach allowed us to gain a deeper understanding in the complex phenomenon of teaching mathematics in ASPETE, thus adding to the related literature (Engelbrecht, Bergsten & Kagesten, 2012; FitzSimons, 2001). The diverse perspectives create the multi-dimensional phenomenon of mathematics teaching effectiveness that was examined through the interplay of factors that shaped the complex environment of contemporary classrooms.

In particular, it was revealed that the students and the lecturer seem to converge with respect to the identification of the qualities of what effective mathematics teaching is. Considering the desired/intentioned level, the students seemed to prefer statistically significant more of the desired qualities, although marginally higher than the conceptual neutral. At the same time, the lecturer's reflections about her actual teaching appeared to justify the students' being satisfied with her teaching, as she showed elements of being aware of her students' needs and of ways to meet them in everyday teaching. This was also, in general, confirmed with our direct observation of her actual teachings. Nevertheless, we did notice aspects that would need to be addressed; for example, the whole group discussions did not serve their role, with less than half of the students usually actively participating.

The latter was essentially reflected on the lecturer's intentioned/desired reality. She seemed to be more concerned about the ways that her future teachings would be more aligned to her intentions. Thus, the lecturer appeared to be more self-conscious with respect to the space and manner of improving her teaching, whereas the students seemed to be relatively satisfied with the current practices.

Moreover, the direct observations helped us to functionally map the pragmatic reality of the class, by noting the time and the manner in which the aforementioned qualities appear, are actually built and interact during the classroom teaching. Such information is of particular importance to this study, as mathematics teaching effectiveness is conceptualised as an 'emergent, systemic phenomenon', and, thus, mapping the qualities of the interlinkings of the various perspectives is crucial.

Consequently, it is argued that the proposed systemic model of mathematics teaching effectiveness is accordance with the existing literature, allowing at the same time for the meaningful 'mapping of the relationships of the mappings' that different perspectives offer. On the one hand, we obtained a mapping of the pragmatic reality of the class system, in which qualities and to what degree mathematics teaching effectiveness is actually experienced by the educational protagonists and the researcher and, by appropriately linking those, the mathematics teaching effectiveness experienced by the class system. On the other hand, we obtained a mapping of the desired/intentioned reality of the class system, in which qualities and to what degree mathematics teaching effectiveness the educational protagonists would prefer to experience. Thus, the proposed methodology (in line with Moutsios-Rentzos & Kalavasis, 2016; Moutsios-Rentzos et al., 2015b) allowed for the identification of the qualities of the space of planifications that the system would be less reluctant to be implemented, which is expected to maximise the effectiveness of future actions with the purpose to improve the mathematics teaching effectiveness of the system.

6. Recommendations

Following these, in our on-going research project (MATHETE), we have utilised these results with the collaboration of the lecturers of mathematics in ASPETE, in order for specific changes to be made that are expected to improve the quality of the teaching and learning mathematics in ASPETE. These changes span across the spectrum of the lecturer-student interactions, drawing upon the specificities of mathematics teaching effectiveness identified mainly during the observations and the interview, as well as the generalities of mathematics teaching effectiveness that are co-identified by the three mappings of this study.

Furthermore, in line with another interdisciplinary research projects with school teachers and principals (Moutsios-Rentzos, Kritikos & Kalavasis, 2019), we use the findings of these analyses to allow for the emergence of a 'communication space', which may serve as the common ground for 'collective reflections of lecturers of mathematics and other disciplines' in ASPETE. Such dialogical and critically reflective practices can shape a specific teaching culture within ASPETE and allow the creation of collaborative learning communities. Considering the twofold orientation, technological and pedagogical, of the ASPETE programmes, as well as the variety and depth of curricula, we posit that

such a communication space of interdisciplinary collective reflections will facilitate the students' constructing meaningful mathematics, as, for example, they may be more explicitly linked and relevant to their current studies and their future career (cf. Kasimatis et al., 2018). These collective reflections will gradually provide the opportunity for novel meanings to be assigned to the teaching and learning experience, thus re-defining the space of teaching and learning mathematics.

7. Conclusions

In this article, we investigated the mathematics teaching effectiveness in ASPETE, a Greek tertiary education institute in Greece, the graduates of which hold an engineering degree and a pedagogical degree. Acknowledging the complexity of the ASPETE institute, we viewed ASPETE as a learning system and we conceptualised mathematics teaching effectiveness as a systemic property. In particular, we focussed on one class and the mathematics teaching effectiveness characterising that system, as emerging through and beyond the experiences of the educational protagonists: the students, the lecturer and the researcher. In our approach, we included both the current lived experiences and the desired lived reality, in order to identify what the class system experienced as mathematics teaching effectiveness and what they would prefer to experience, thus facilitating the design and implementation of actions that are expected to improve mathematics teaching effectiveness and would be more likely to be accepted by the system. Consequently and importantly, for our study, our linking of the results of the three analyses allowed us to reveal convergences and divergences of the conceptions of what happened and what would be desired to happen that may be utilised in designing appropriate and specific needs of the particular system planifications, in order to improve the effectiveness of mathematics teaching within the particular educational system.

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