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Research Article

The impact of changing environment on undergraduate mathematics students' status

Mario Lepore [1]
0000-0001-9858-9420

Roberto Capone [2*]
0000-0001-9454-8453

[1] University of Salerno, Fisciano, ITALY
[2] University of Study Aldo Moro, Bari, ITALY
[*] Corresponding author: roberto.capone@uniba.it

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ABSTRACT

This paper focuses on the impact of changing environment on undergraduate mathematics students' status, described through their engagement, participation, and motivation levels. These parameters were computed through a fuzzy cognitive map, which gathered data from a situation-aware e-learning platform. The main goal is to analyze the students' reaction to a long-term emergency caused by the COVID-19 pandemic. A mixed-methods case study was conducted at University of Salerno to evaluate how completely remote teaching for the second year influenced the student's status. The results show that distance learning and other social factors decrease university mathematics students' motivation, engagement, participation, and overall performance in the long term, despite the countless teaching strategies implemented, the consolidated combination of mathematics and technology, and the use of a situation-aware e-learning platform.

Keywords: case study research, e-learning, fuzzy cognitive maps, undergraduate mathematics education, mixed-methods

INTRODUCTION

The emergence of information and communication technologies (ICT) has brought about significant changes in society and education. This has led to the emergence of research on new forms of learning and epistemological questions about the process of learning and knowledge acquisition beyond traditional education systems. As a result, a creative space has been opened, where learning, innovation, and work can be integrated (Hakkarainen, 2009). The introduction of ICT has also led to the emergence of a new generation of students, which has been referred to in various terms such as "digital natives" coined by Prensky (2001), "homo zappiens" marking the transition from homo sapiens by Veen and Vrakking (2006), "net generation" or "instant generation" (Oblinger & Oblinger, 2005).

In mathematics education, technology in teaching and learning has a long tradition. Some universities have been delivering mathematics courses in a blended mode for many years. Massive open online courses (MOOCs) for mathematics have also been introduced worldwide by various institutions such as Stanford University, University of Michigan, Universitat Politecnica de Valencia, Hong Kong University of Science and Technology, and University of Turin. In addition, dynamic geometry software has been commonly used in university courses to support learning in mathematics topics such as one and several variable functions, 3D-geometry, linear algebra, and others. Several studies in the literature demonstrate the meaningful use of technologies such as augmented reality (AR) and virtual reality (VR) can help overcome some of the difficulties encountered in learning mathematics (Cahyono et al., 2020).

In mathematics, technologies are supposed to be used to support working with multiple representations (Duval, 2006), discovery learning (e.g., Hoyles et al., 2013), individual learning, and reflection (Mitchelmore & Cavanagh, 2000). These studies specifically involve researchers from several fields, including sociology, cognitive psychology, computer science, pedagogy and mathematics education experts. Scholars in cognitive and socio-cultural theories have emphasized numerous beneficial aspects of technology in the realm of mathematics education. The emphasis on action, particularly in fields like neuroscience, enactivity, and simplexity, has shed light on the interconnected nature of action and knowledge, as well as the interplay between action and perception (Berthoz, 2003; Rivoltella, 2012) and the role of technologies in these processes. Since the relationship between experience and conceptualization is at the basis of learning processes in the educational field, it becomes central to understanding how digital artifacts impact the process of educational mediation, modifying both the artifacts and the awareness that users have of them. In the area of Mathematics Education, recent studies (Aldon et al., 2019) have highlighted how visual-kinesthetic activities can help students to experience multiple levels of sophistication and develop the multiple meanings of covariational reasoning (Swidan et al., 2019). Since technologies were seen as an enhancement for mathematics teaching, most mathematics educators were ready for a radical technological change, rejecting the old forms of knowledge transmission and extending learning environments to virtual ones. Nevertheless, when the school system was challenged severely during the COVID-19 pandemic, i.e., when it came to conducting a full-scale distance learning test, the results were not as hoped for. Students have experienced moments of intense emotional stress, with the risk of generating a state of frustration and discouraging them from studying. We were suddenly faced with a drastic change in our lifestyle, reviewing the priorities of our needs. It was not just a question of using technologies in mathematics teaching but an actual adaptive process to the exclusive use of technologies as the only way to teach. The compulsory use of distance learning as the only means of teaching in schools and university courses has brought with it a variety of doubts and questions to be addressed; some of them were, as follows:

1. What didactic strategies should the mathematics teacher adopt to ensure students acquire the same skills as face-to-face teaching?
2. How can students' interests be kept alive? How do you stimulate them to follow the lessons at a distance in an emergency?
3. Which aspects of mathematics teaching at blackboard are compromised with distance learning in a context of emergency?

Answering these and other questions was crucial for the mathematics teachers to not leave the students adrift in their learning process. Specifically, it is not uncommon for many students to drop out of their studies due to the first obstacles encountered in introductory mathematics courses, especially STEM students. They consider the mathematics exams a sacrifice to be expiated to proceed with their studies (Capone, 2022). This becomes even more pronounced if we refer exclusively to online courses. It is not rare to find many students who leave the online learning course shortly after the beginning; such a phenomenon, called drop-out, is always more frequent among students who are not sufficiently engaged and motivated with the learning experience (Levy, 2007). The root causes of students dropping out are a lack of motivation, engagement, and participation (Keller & Suzuki, 2004). The motivation (Lepper, 1988) considers the level of interest in the course, the engagement represents the level of involvement in the learning experience (Kuh, 2003; Xiong et al., 2015), whereas participation (Dominguez, 2012; Li et al., 2020) refers to the action of taking part in activities and projects, the act of sharing in the activities of a group. According to the authors' previous works, one of the main objectives of this work, which is in continuity, is to investigate the possible effects of the long-term use of distance learning as the only means of mathematics teaching in an emergency, in addition to other social factors, on students' motivation, engagement, and participation. The authors' previous works highlight the importance of using information technologies in the educational dialogue to prevent drop-out and improve students' engagement, motivation, and participation (Capone & Lepore, 2022). In addition, the contribution that the numerous teaching strategies implemented and the use of a situation-aware e-learning platform, recently updated (Capone et al., 2022) had on the students' level of mathematical competence was analyzed. From these premises, the research questions can therefore be summarized, as follows:

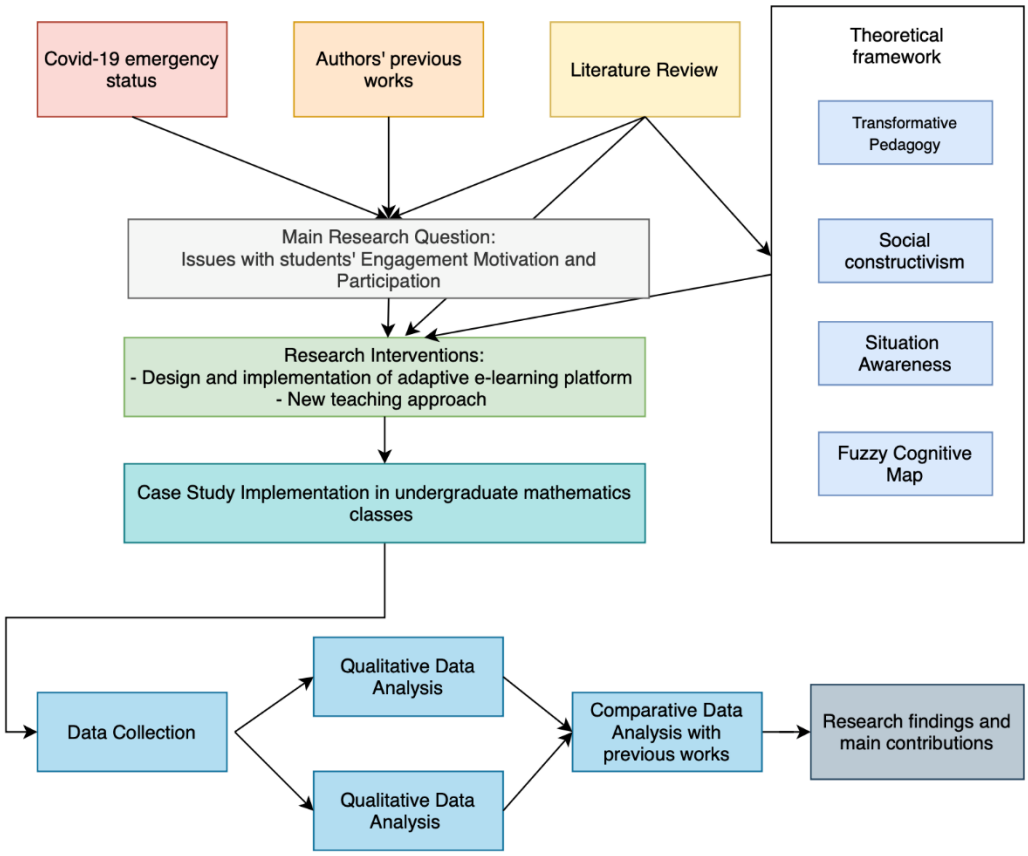

Figure 1. Research process (Source: Authors)

RQ1. How do engagement, motivation, and participation, in undergraduate mathematics class, change with fully distance learning extended for a second year in an emergency?

RQ2. Can a custom situation-aware e-learning system and personalized teaching contribute to effective mathematics teaching in terms of competencies acquired by students in this context?

The research described in this academic paper focuses on first-year engineering students attending the calculus II course at University of Salerno during the 2020/2021 academic year. Due to the pandemic, these students attended their final year of high school and first-year university courses entirely at a distance. The calculus II course was also conducted remotely during the first year's second semester. A mixed-methods approach was used to collect quantitative and qualitative data for the case study. The results were compared with previous experiments conducted in a blended mode during the 2018-2019 academic year and completely remotely during the 2019-2020 academic year. The collected data indicates that distance learning and social factors negatively impact students' motivation, engagement, participation, and mathematical competence, leading to increased drop-out rates. However, the authors' efforts to adapt their teaching approach and utilize an updated e-learning platform helped mitigate some negative effects and achieve acceptable success. **Figure 1** depicts the process of how the authors carried out their work.

The authors have previously detailed the theory of situation awareness, the description of the e-learning platform, and the ad-hoc fuzzy cognitive map (FCM) map developed through a consensus process, which served as a tool to describe and model the students' situation. In this manuscript, the subsequent sections are structured, as follows. Next section provides a literature review that outlines the latest approaches to enhancing students' motivation, participation, and engagement. Then we describe the conceptual framework of the experimentation. After that we detail the methodology used. We then present the data collected from both qualitative and quantitative analyses. Then, discussion is presented. Finally, we address the study's limitations and conclude with final remarks and recommendations for future research.

RELATED WORKS

Numerous research experiments have examined the use of technology in mathematics teaching and learning in mathematics education, with the goal of enhancing students' levels of engagement, motivation, and participation (Arzarello & Robutti, 2010; Heid, 2005; Swidan & Faggiano, 2021).

Some scholars, such as Biggs (2011) and Biggs and Tang (2010), have sought to address the transmissive nature of traditional teaching methods and proposed a constructive alignment approach that emphasizes what is taught and the intended learning outcome. Kaput and Thompson (1994) employed a metaphor of deep-water ocean waves to describe the complex interactions between technology and research in mathematics education. This metaphor accurately captures the behavior of waves, swells, and tides in the ocean. Waves occur at the surface and are influenced by local conditions such as wind and eddies. Swells are of longer duration and are affected by larger-scale local conditions such as temperature and currents. Analyzing wave behavior over extended periods and placing it within the context of interacting forces is necessary to distinguish waves from swells. Finally, tides originate from the frames of reference for swells and waves and are measured over periods of magnitude greater than the others. Studying any level of wave activity in isolation is possible, but the different activity levels interact in subtle yet significant ways.

These works are generally helpful in analyzing blended teaching methodologies and applications in which some technologies are used in mastery teaching. This research analyses a new situation in which university teaching was delivered entirely at a distance due to an emergency.

Teachers and students have shown alterations in such a context, especially in their emotional states.

Over the past two years, numerous scholars have examined the COVID-19 pandemic from various perspectives. Some researchers have investigated the impact of the pandemic on students and teachers regarding teaching, social, and psychological aspects (Yilmaz et al., 2021). Bakker et al. (2021) have questioned whether the pandemic has shifted the focus of research in mathematics education to address social and educational issues. Other authors, such as Siregar and Siagian (2021), have evaluated the shift towards online mathematics learning, including developing new teaching methods and focusing on solving social problems such as climate change and species extinction. However, they have also identified issues related to the lack of interaction between instructors and students using online communication media such as WhatsApp. Meanwhile, Alabdulaziz (2021) and Brunetto et al. (2021) have described alternative approaches to organizing distance learning, such as utilizing mathematics resources and laboratory activities. Authors in various countries have also reported on the challenges of teaching during school closures, including difficulties associated with economic factors, teachers' ability to adapt quickly to changes in teaching, and limited internet access (Azhari & Fajiri, 2021; Borba, 2021). Furthermore, a special issue of Educational Studies in Mathematics (Chan et al., 2021) has compiled research findings on teaching mathematics during the pandemic from international researchers. Finally, Rutherford et al. (2021) have used data from a mathematics learning software to examine students' engagement and motivation during the pandemic, finding that students exhibited reduced engagement with the software and decreased motivation towards mathematics. Results illustrate the potential and pitfalls of using educational technology data instead of traditional assessments and draw attention to access and motivation during at-home schooling.

CONCEPTUAL FRAMEWORK

This section outlines the conceptual framework that the conducted experimentation pertains to. Specifically, we describe the framework of the transformative pedagogy (Mezirow, 1997), which helps us comprehend how students, who find themselves within critical moments of their lives, manage to overcome themselves, their fears, and anxieties. In this way, they accept and understand the "new" and become more aware of and suited to the uncertainty that characterizes their existence. We describe the idea of ZPD, an essential element of socio-constructivism theory as proposed by Vygotsky (1978). The Vygotskian socio-cultural approach helps us understand how the causal relationship between social interaction and individual cognitive change has been crucial in these pandemic years to explain certain educational phenomena. Here it is used as a theoretical lens to better interpret the student's motivation, participation, and engagement to which the concept of ZPD seems to be related.

Transformative Pedagogy

We will describe the theory of transformative pedagogy (Mezirow, 1997) and how it is used to analyze the teacher's educational activities and the students' reactions. The aim is to determine whether the changes in teaching methods brought about by the crisis are sustainable in the long term or whether they are merely temporary adaptations to current circumstances. As per Mezirow's (1997) transformative learning theory, learning entails expanding one's consciousness through the transformation of fundamental worldviews and specific self-skills. Within the context of transformative learning, certain didactic conditions may arise, ultimately leading to the process of "perspective transformation," which manifests across three distinct dimensions, as follows:

1. The psychological dimension, involving changes in self-understanding.
2. The conventional dimension, involving a revision of one's beliefs.
3. The behavioral dimension, involving changes in one's lifestyle.

Mezirow (1997) posits that perspective transformation, which ultimately leads to transformative learning, typically occurs in response to a "disorienting dilemma" triggered by a life crisis or significant transition. However, it may also result from a gradual accumulation of transformations into patterns of meaning over time. A key aspect of transformative learning is that individuals, including educators and learners, shift their frames of reference by critically reflecting their assumptions and beliefs, consciously implementing and realizing plans that establish new ways of defining their worlds through a rational and analytical process. The learning process is inherently linked to the notion of change, specifically the evolution of one's status. The analysis of the student's educational needs is vital for the effectiveness of the teaching-learning process, as change encompasses these needs. However, it is important to note that not all change leads to transformation. This paper examines some educational aspects of distance learning that may contribute to a paradigm shift in educational teaching. These include using social platforms in the learning curriculum, incorporating a platform to manage certain aspects of university distance learning, and integrating video lessons with more traditional didactic approaches through a YouTube channel.

Zone of Proximal Development as Strategic Relationship

According to Vygotsky's (1978) definition, ZPD is the gap between a learner's current developmental level, as determined by their ability to independently solve problems, and their potential developmental level, as determined through problem-solving with guidance from a more capable peer or adult. This concept appears to be closely linked to the learner's motivation, participation, and engagement (Laurillard, 2007). Motivation is inherent when working within ZPD because it involves transferring control over learning from the teacher or more capable other to the learner, acknowledging their mastery of the task and contributing to their sense of efficacy. Interaction within ZPD is also likely to pique the learner's interest in the task or knowledge domain, as they come to value the knowledge espoused by a respected, more capable person. Furthermore, as learners gain mastery in a knowledge domain, they are more likely to appreciate its relevance and value.

ZPD can also be considered a relational or affective zone (Goldstein, 1999) created through sensitive and trusting relationships between students and their teacher, developed through supportive activities promoting learner confidence and positive emotions. Considering ZPD as a shared affective zone has important motivational implications, as the emotional quality and tone of interactions within ZPD and the sense of caring fostered by these interactions can significantly impact students' engagement in learning and their willingness to take on challenges. However, some characterizations of ZPD overlook the sociocultural implications of cooperative learning interactions on content knowledge acquisition. It is crucial to recognize that social interactions and learning content knowledge are intricately linked in ZPD, each influencing the other in a dynamic and reciprocal relationship. Ignoring this interplay between social interactions and content knowledge acquisition may result in partial characterizations of ZPD that fail to capture its full implications.

ZPD, as defined by Vygotsky (1978), encompasses more than just cooperative learning. In fact, ZPD can be present even in seemingly solitary activities such as studying, as individuals necessarily rely on socially mediated knowledge to participate successfully in these activities. Therefore, assuming that cooperative learning is the only way to create a ZPD is a misunderstanding that results from a failure to consider the transformation of socially defined knowledge. Internalization is a process that transforms social phenomena

into psychological phenomena. When knowledge is constructed within its context of use, it cannot reside solely in the minds of individuals. According to Vygotsky (1978), learning always occurs within a social context, and instructional strategies that promote expert knowledge distribution and collaboration among students help create a collaborative community of learners.

Vygotsky's (1978) socio-constructivism has led to the development of the concept of a "sense of community" (McMillan & Chavis, 1986). This sense of community goes beyond physical encounters and extends to virtual communities. With distance learning, the concept of community becomes a "network of practice" (Nichani & Hung, 2002), and the same Vygotskian socio-constructivism concepts can be applied. However, the question remains whether emotions shared in a virtual environment can replace the emotions experienced through physical contact in the long term.

In ZPD, student motivation, participation, and engagement are inherently linked to the transfer of control for learning from the teacher or more capable other to the learner. This transfer of control acknowledges student mastery of the task and promotes the learner's developing efficacy. As learners achieve mastery in a knowledge domain, they are more likely to appreciate the relevance and value of that knowledge domain. Interaction within ZPD also leads to the recruitment of the learner's interest in the task or knowledge domain as they value the knowledge that a more capable person respect.

ZPD is both a cognitive and a relational or affective zone. Goldstein (1999) characterizes ZPD as a socially mediated space formed through sensitive and trusting relationships. In a classroom, this space is created through interactions between students and their teacher as they engage in supportive activities that develop learner confidence and positive emotions. The emotional quality and tone of interaction in ZPD and the sense of caring engendered can have important implications for students' engagement in learning and willingness to challenge themselves.

In summary, a complete characterization of ZPD assumes that students always participate in something, even when they do not participate in intended curricular activities. ZPD can be present in solitary activities such as studying, as individuals rely on socially mediated knowledge to participate successfully. Vygotsky's (1978) socio-constructivism emphasizes the importance of collaboration among students and expert knowledge distribution to create a collaborative community of learners. ZPD is not just a cognitive but also a relational or affective zone that involves relationships formed through sensitivity and trust. The emotional quality and tone of interaction in ZPD can have important implications for students' engagement in learning and willingness to challenge themselves.

METHODOLOGY

The research discussed in this statement is grounded in the socio-constructivist perspective on learning. This perspective emphasizes the importance of the context in which learning takes place, including the classroom and sociohistorical factors that may influence learning outcomes. In addition, the research recognizes the interconnected nature of cognitive, motivational, and affective factors in students' learning. In order to answer the two research questions that the authors identified as the cornerstones of this paper, mixed-methods research (Creswell, 2015) study was conducted. All the research steps (from identifying the objectives questions to constructing the theoretical framework and hypotheses) were performed closely and constitute a unified study in which the two moments cannot be separated. Specifically, both qualitative and quantitative methods were used to analyze aspects related to the effects of forced and long-term use of distance learning on student situation, defined through the parameters of engagement, motivation, and participation, and on their mathematical skills. For our purposes, a situation can be intended as the current state of the learner with respect to her experience with the learning process of mathematics also through the use of technological tools. A learner, which has a good situation awareness is a learner that is perfectly aware of her current learning progresses, learning objectives, difficulties in solving problems, tasks to complete, and so on. The implemented e-learning system needs an operational representation of the situation that is focused on the main objective of supporting students in learning mathematics. As a situation identification technique, we used an approach based on FCM (Kosko, 1986). The aim of our FCM (as shown in **Figure 2**) is to encompass the effects of all the variables identified in the situation model by a team of five mathematics education experts. These variables impact the engagement, motivation, and participation of the learner,

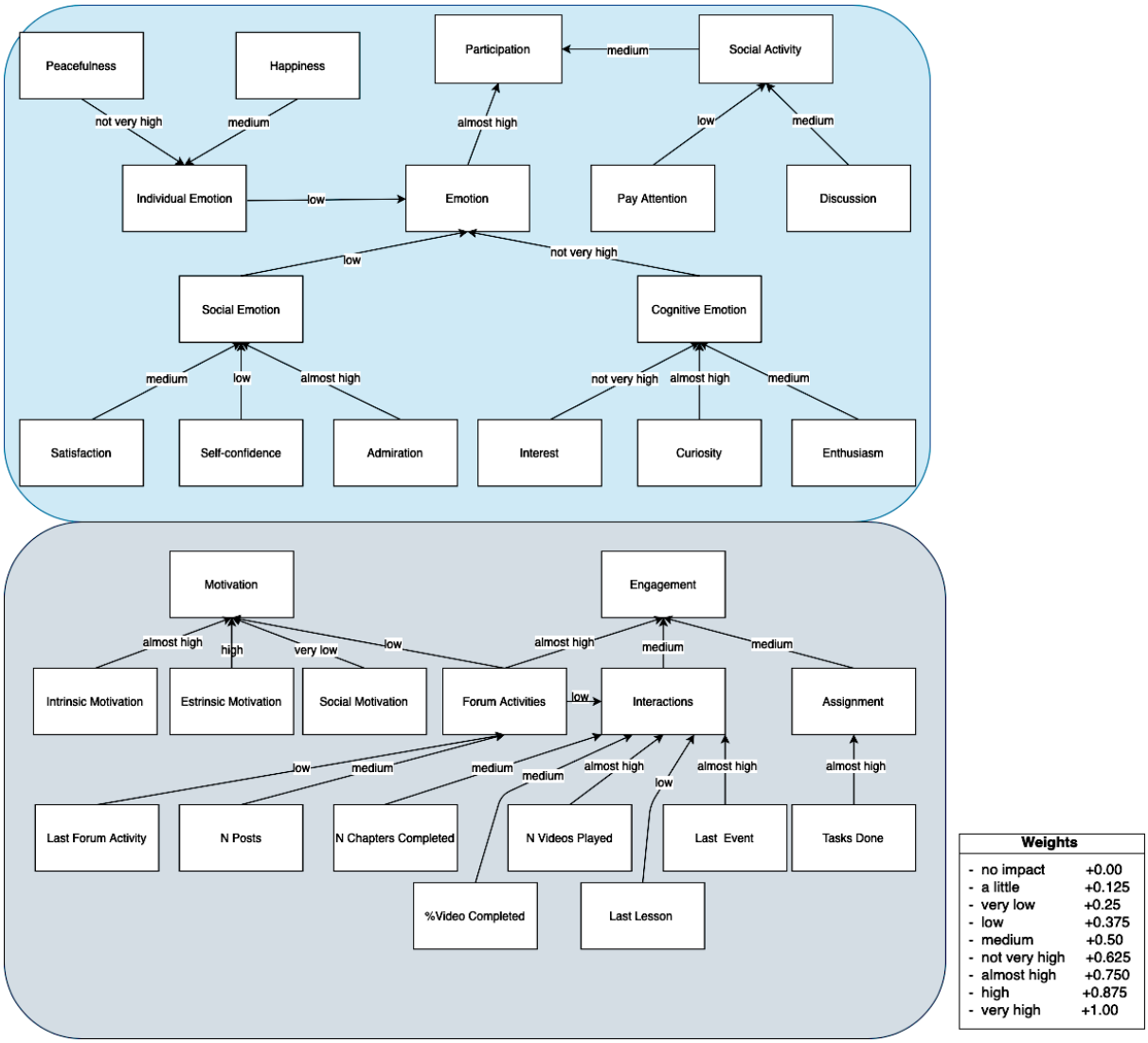

Figure 2. FCM for situation identification (Capone & Lepore, 2020)

Table 1. Likert scales statements of agreement, frequency, & satisfaction

Agreement	Frequency	Satisfaction	Value
Strongly disagree	Never	Not at all satisfied	1
Disagree	Rarely	Slightly satisfied	2
Undecided	Sometimes	Moderately satisfied	3
Agree	Often	Very satisfied	4
Strongly agree	Always	Completely satisfied	5

which are the three overarching concepts that represent the learner's current situation. Using this model, the system can fulfil a dual function: supporting the student in her mathematics learning journey through adaptive feedback and providing analytics to the teacher on the status of her students. Furthermore, the methodologies used for the qualitative and quantitative analysis were, as follows:

1. A questionnaire, created in Google Forms, was used to obtain some of the data necessary for qualitative and quantitative analysis, i.e., to bring out elements helpful in delineating the student's status according to the proposed model. The questionnaire included hierarchical questions in which students ranked several modes of a phenomenon in order of importance, based on the 5-level Likert scale, as shown in **Table 1**, and open-ended questions through which the respondent was free to express herself in the form she preferred; the former was designed so that the student's emotional state could be inferred; the latter were worded so that their motivation could be deduced.

2. By analyzing the protocols derived from the educational dialogues between students and teachers using the proposed e-learning system, it was possible to obtain other qualitative information helpful in delineating the social aspects.
3. FCM (**Figure 2**) summarizes qualitative and quantitative data collected through the platform regarding participation, motivation, and engagement, allowing comparison with data from previous cohorts.

The parameters pertaining to motivation were determined by analyzing questionnaires that were administered during the course. The parameters related to participation, emotions, and social activities were established through sentiment analysis of the video streaming from the webcams capturing students' activities, as well as through the responses provided in the questionnaire. The engagement parameters were obtained through the systems used to collect student interactions, which made them accessible for analysis. Regarding the analysis of disciplinary competencies, a comparison was made between the first and second midterm tests of the cohorts of students of the three academic years under examination, considering the grade-competence assessment grid (A-advanced, B-high, C-medium, D-initial).

To experiment, the data of interest were collected and analyzed in the classes of calculus II of mechanical/management engineering at University of Salerno in the academic years 2018/2019, 2019/2020, and 2020/2021. The 2018/2019 course was held in person through blended teaching, alternating traditional teaching with technological tools (for example, AR devices). At the same time, the 2019/2020 and 2020/2021 courses took place at a distance. The three classes were 131, 112, and 98 students, respectively. Cochran's (1963) formula was used to calculate the sample size for the experimentation: $n_0=Z^2pq/e^2$, where e is the desired level of precision (i.e., the margin of error), p is the (estimated) proportion of the population that has the attribute in question, q is 1-p, and the z-value is found in a Z table. It is s the abscissa of the normal curve that cuts off an area α at tails (1-α equals the desired confidence level, e.g., 95%); n_0 is the sample size. In our experimentation the chosen parameters were Z=2.33, p=0.90, and e=0.10 for the part of the experimentation that concerned the analysis of engagement, motivation and participation and led to a sample of 60 people.

RESULTS

This section reports qualitative and quantitative data, highlighting the main research findings. Data about students' engagement, motivation, and participation are analyzed from a quantitative point of view and a qualitative point of view. The results of students' competencies are also reported.

Engagement Motivation and Participation Quantitative Analysis

In this subsection, the data about students' engagement, motivation, and participation are analyzed, comparing the results of these parameters obtained in the academic years 2018/2019, 2019/2020, 2020/2021. In the academic year 2018/2019 it has been used a blended learning, whereas in the academic years 2019/2020 and 2020/2021, full distance learning was used.

Figure 3 shows the average input values for the middle layer FCM concepts.

The comparison of the three groups of students in the sample is depicted in the three graphs. The first group, represented in blue, pertains to "blended learning 2018/2019," which includes students who attended classroom lessons and utilized the reference e-learning platform during the academic year 2018/2019. The second group, shown in orange, represents "distance learning 2019/2020," comprising students who completed the course entirely online during the academic year 2019/2020. The third group, illustrated in grey, represents "distance learning 2020/2021," consisting of students who also completed the course entirely online during the academic year 2020/2021. The first three parameters analyzed in this study, namely individual emotion, social emotion, and cognitive emotion, reflect the emotional states of the students, including peacefulness, happiness, satisfaction, self-confidence, admiration, interest, curiosity, enthusiasm, pay attention, and discussion. The data reveal that the academic year 2018/2019, which employed blended learning, resulted in a more positive emotional state among the students. In contrast, the emotional state of the students in the academic year 2019/2020 was impacted by the pandemic emergency. The drop in these parameters manifested by students in the 2019/2020 year is even stronger in the second year of distance learning. As a result of the inference on pay attention and discussion levels, social activities parameter

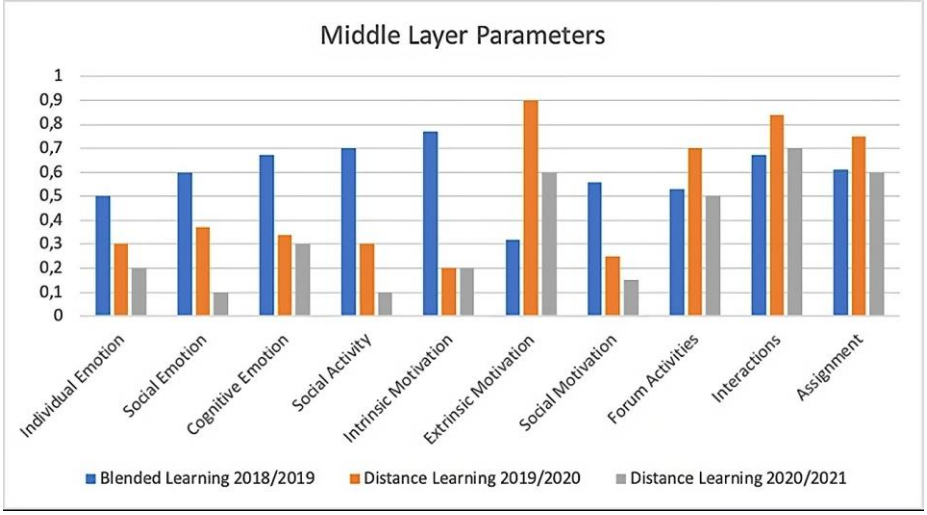

Figure 3. Middle layer results computed through FCM (Capone & Lepore, 2022; Capone et al., 2022b)

plummeted from blended learning to the second year of distance learning, despite teachers' efforts to encourage social dialogue among students during class.

The present study highlights notable distinctions amongst the parameters relating to motivation, specifically intrinsic motivation, extrinsic motivation, and social motivation, across the three academic years. Specifically, during the 2018/2019 academic year, students demonstrated a self-driven desire to participate in the course and engage in the activities offered by the instructors, motivated by the desire for personal enrichment and to partake in a shared experience with their peers. Conversely, students during the 2019/2020 academic year were subjected to an external constraint compelling them to pursue the online course as the sole means of satisfying attendance requirements to gain access to the final examination.

The situation was even worse in the 2020/2021 academic year in which the motivation for being able to take the exam was not enough to take the course. Confirming this index, few students attended the final exam: in the academic year 2018/2019, 66% of the students attended the first available exam. In the academic year 2019/2020, 67% of the first available exam, in the academic year 2020/2021, 42% of the first available exam. Forum activities, interactions, and assignment, or the parameters related to engagement, show balanced levels over the three years. Having the e-learning platform as the only tool available to access the teaching material and to carry out the exercises, the students of the academic years 2019/2020 and 2020/2021 show a comparable level of interaction to the students of 2018/2019, where the use of the platform was an additional part, used to integrate with some extra activities what was done in the presence.

The average levels of engagement, motivation, and participation calculated through the execution of FCM are shown in **Figure 4**, which summarizes what is reported in the analysis of the data of the middle layer parameters. Despite the difficulties and digital barriers of fully distance learning, students were motivated (even if extrinsically) to attend classes and engage during the first year of the pandemic. They interacted with teachers and through the e-learning platform. Distance learning was experienced as a moment of being together. During the second year of the pandemic, students seemed more unmotivated. Interest and participation in the activities offered on the e-learning platform seem to have decreased. This finding emerges from the graphs shown in **Figure 4**. During the first year of the pandemic (2019/2020), even the parameters of engagement and motivation, although in modest amounts, are higher than in the year 2018/2019. The same graph shows how all three parameters collapsed during 2020/2021.

Finally, the drop-out graph in **Figure 5** shows that 2018/2019 (6%) and 2019/2020 (9%) are comparable. Despite the difficulties of distance learning, the phenomenon was fairly contained. Also, in 2020/2021, the teachers have activated teaching strategies to promote students' educational success. Despite the efforts and changes made to the e-learning platform, the drop-out in 2020/2021 (16%) has almost doubled compared to the previous year.

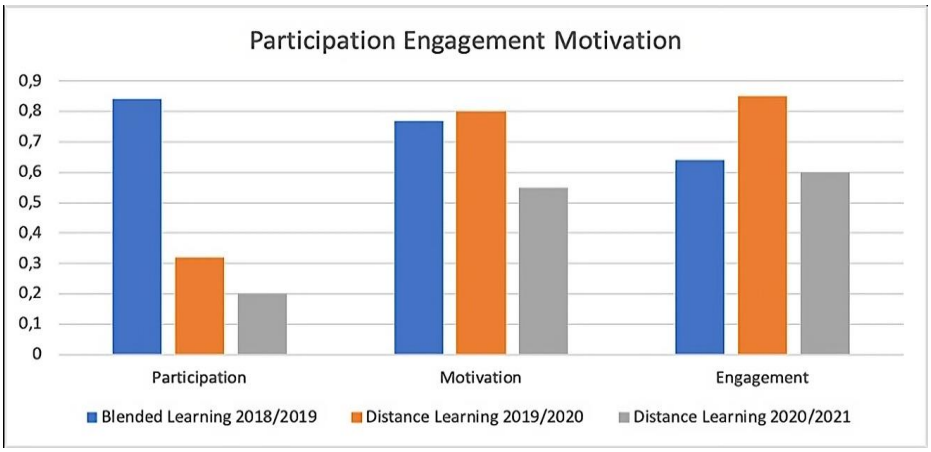

Figure 4. Participation, engagement, & motivation results computed through FCM (Capone & Lepore, 2022; Capone et al., 2022a)

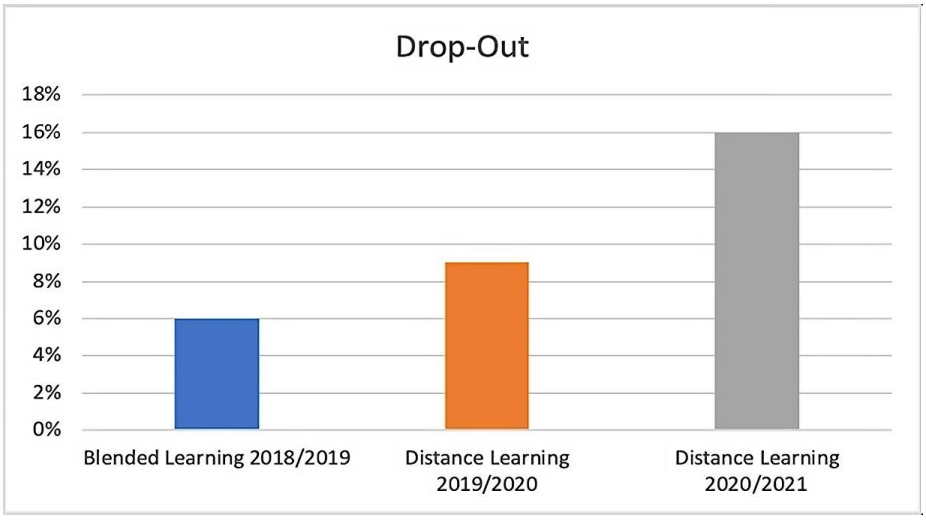

Figure 5. Drop-out results (Capone & Lepore, 2022)

In addition, beyond using FCM as a tool for quantitative analysis, data gathered by Likert scale questionnaires administered to students each year at the end of the course were used for comparative analysis. It emerges that in the year 2020-2021, 64% of students answered 4 or 5 on the Likert scale to the question of how frequently they confronted each other on the teaching activities of the course using digital tools; while in 2018-2019, 40% and in 2019-2020 69.77%. The 62,2% of the students stated that they had interacted on the e-learning platform forum either assiduously or very frequently (4 or 5 on the Likert scale) in the year 2020-2021. This value is higher in 2019-2020 (92%). As they declared, the forum allowed them to recreate the study room environment, although virtual, to discuss the solution to the exercises proposed in class. In 2018-2019, however, only 25%.

Engagement Motivation and Participation Qualitative Analysis

The quantitative data analyzed through FCM seem to be confirmed by the qualitative results that emerge from the analysis of the students' answers to the anonymous questionnaire given at the end of the course. From the questionnaire sent to the students and the social dialogues between students and between students and teachers on the e-learning system, information was obtained regarding the parameters of participation, engagement, and motivation. The questions concerned mainly how students felt about learning activities and social dialogue, how motivated they were in taking classes and studying, and their relationship with e-learning platform. Regarding motivation parameter, following most common students' answers were extracted:

Table 2. Results of the tests done by students during the two academic years

Mark	First mid-term test 2018/2019	First mid-term test 2019/2020	First mid-term test 2020/2021	Second mid-term test 2018/2019	Second mid-term test 2019/2020	Second mid-term test 2020/2021
A	4.0%	6.0%	10.0%	15.0%	10.0%	14.0%
B	12.0%	17.0%	12.5%	18.0%	15.0%	10.5%
C	31.0%	30.0%	42.5%	23.0%	31.0%	36.0%
D	22.0%	19.0%	12.5%	12.0%	15.0%	29.0%
Fail	32.0%	25.0%	22.5%	32.0%	28.0%	10.5%

> S1: After almost two years of distance learning, there seems to be no end to this situation. I feel very unmotivated, even to study.

> S2: I often spend entire days on the computer. I get tired quickly and often don't feel like attending classes in their entirety.

As can be seen from students S1 and S2, students' confidence in returning to face-to-face teaching has plummeted. This has led to a significant drop in motivation compared to previous years. Whereas, regarding the participation parameter, the following most common students' answers were extracted:

> S3: Not being able to study on-site and deal with the professor and other students in person made me sad. The lack of socialization with the rest of the group completely turned my enthusiasm for studying.

> S4: Participating in in-face-to-face classes makes it much easier for me to learn. I find it difficult to take courses at a distance because of too many distractions and the lack of my classmates' presence supporting me in my studies.

> S5: It was very challenging to take the course at a distance because of the loss of what is student-class-teacher interaction. Better future teaching could keep together in-person and distance modes.

The participation parameter is the one that has been affected the most. This emerges from the responses of students S3, S4, and S5 that confirm the data analyzed through FCM. Student S5 emphasizes the link between the difficulty of taking the course and the lack of interaction with peers and the professor. But what seems to be common to most of students' answers is negative effect of this emergency on their emotional state. Finally, regarding engagement parameter, following relevant students' answers were reported:

> S6: The professors do their best to make us follow the course profitably, providing us with supplementary materials easily available on the e-learning platform.

> S7: The feedback on the platform has been constructive in clarifying doubts, especially on more advanced topics.

> S8: On the e-learning platform, we found all the material needed to take the exam, but I often didn't want to log on because I had already spent too many hours on PC.

The words of S6 and S7, also shared by other students, reveal how the platform allows using considerable digital content in a structured way to support teaching in terms of theoretical and practical aspects. S8 highlights an essential element of such a long-standing emergency: although the platform was well designed and helpful for the study, the emergency caused disengagement.

Competencies Assessment

This section compares student performance on the two mid-term tests in **Table 2**. The percentages for 2020/2021 seem to show an improvement in skills over previous years. However, one key finding must be considered that is discouraging, as shown in **Figure 6**. In 2020/2021, only 40 out of 98 students participated in the first intercourse test: 28 students in the second. There was a 35% drop from 2019/2020 and a 45% drop

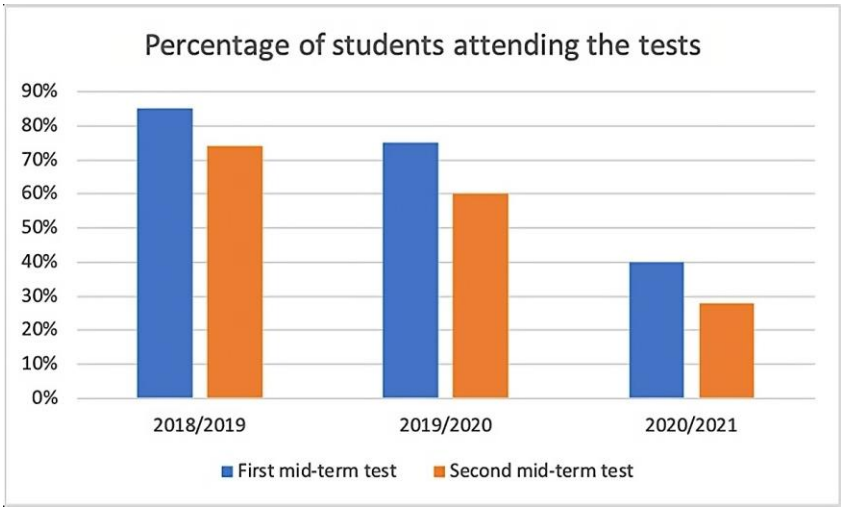

Figure 6. Percentage of students attending the tests (Capone & Lepore, 2022)

from 2020/2021 for the first intercourse test. A decline was also confirmed in the second test and was 32% compared to 2019/2020 year and 46% compared to 2018/2019 year. This situation is reported in **Table 2**.

These data highlight that the efforts made by the teachers to ensure students' educational success seem to have shown positive results. Students who have consistently followed the course and participated in the activities on the e-learning platform have been successful in the exam. However, the discouraging fact is the small number of students who have passed the tests.

DISCUSSION

In this section, the main research findings considering the research questions reported in the introduction of the paper, are discussed. Specifically, this work is based on a mixed-methods methodology to integrate high-level extension studies (typical of the quantitative paradigm) and specific, in-depth studies (typical of the qualitative paradigm).

The quantitative approach suggests the instructional, educational, and training strategies that might work under conditions. The qualitative approach provides information regarding why specific systems work, i.e., under what dynamics and how. From the qualitative analysis of previous studies, the authors found that students' perceptions of using digital tools to support mathematics teaching differed in the years 2018/2019 and 2019/2020.

As sketched in **Figure 7**, in 2019/2020, students perceived technology as the only way to proceed with their studies while maintaining contact with their peers and teachers. Whereas in the academic year 2018/2019, students were excited to use an e-learning platform to support their studies. In 2020/2021, students have perceived the use of technology as an obstacle between the teaching experienced in university classrooms and the learning confined within their rooms. The term obstacle here is an obstruction that students intend to overcome to return to their social lives.

These qualitative data are also confirmed by the quantitative analysis conducted through the study of questionnaires using the Likert scale and the results obtained from the execution of FCM. The mixed-method analysis shows that in 2020/2021, the use of technology to support teaching was less effective than in the previous two years. Students appear to be tired of experiencing teaching in isolation; the prolonged emergency has negatively affected the emotional status of students, who are easily distracted and have little motivation to attend class.

We gathered one of our research's most important practical implications from these two types of analysis: distance learning was less effective than in previous years. Despite teachers' efforts to provide effective teaching (as confirmed by the students' answers), there was a lack of social interaction and confrontation between students and between teacher and student. The network community they tried to build did not fully meet the need for direct interaction. Knowledge sharing also occurs through the emotions that arise from

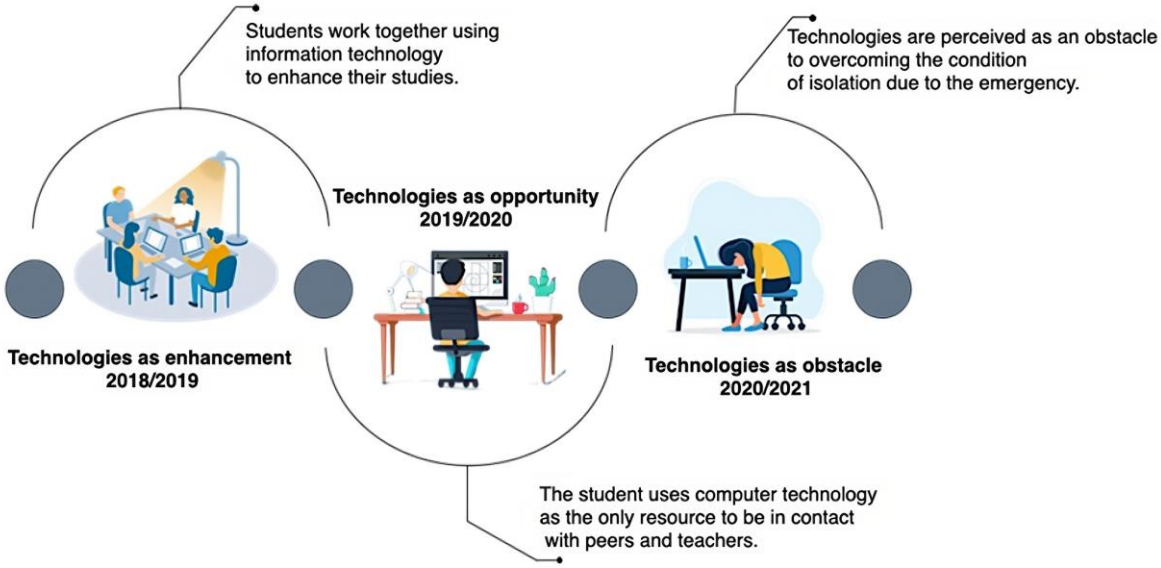

Figure 7. Evolution of students' perceptions of technology (Source: Authors)

social dynamics and fuel motivation and engagement. The COVID-19 pandemic has had a significant impact on students' lives, and it is likely that many have experienced changes in the three dimensions of transformative learning. Here are some potential ways that students' status may have changed during the pandemic:

1. **Psychological dimension:** The pandemic may have led to changes in students' understanding of themselves and their emotions. For example, students may have experienced increased stress, anxiety, or depression due to the disruption of their daily routines and social connections. They may also have had to adapt to new roles and responsibilities, such as caring for family members or adjusting to online learning environments.
2. **Conventional dimension:** The pandemic has challenged many of our assumptions about the world, such as the stability of social institutions and the reliability of scientific knowledge. Students may have had to revise their beliefs about the importance of social distancing, the efficacy of vaccines, or the role of government in addressing public health crises. They may also have had to confront issues of inequality and social injustice, as the pandemic has disproportionately affected marginalized communities.
3. **Behavioral dimension:** The pandemic has forced many students to change their behaviors and adapt to new circumstances. For example, they may have had to switch to remote learning or adjust their study habits to accommodate online classes. They may also have had to adopt new safety measures, such as wearing masks or avoiding large gatherings. The pandemic may have also prompted some students to engage in new forms of social action, such as volunteering to help others or advocating for policy changes to address the pandemic.

Overall, the pandemic has likely triggered a period of reflection and adaptation for many students, leading to changes in their understanding of themselves, their beliefs about the world, and their actions and behaviors. These changes may have been challenging, but they also offer opportunities for growth and transformation. What did happen from a socio-cultural perspective?

Following Vygotsky (1978), "we become ourselves through others". So, context played a key role. The anxieties, stress, and lack of leading a normal life emphasized by the absence of sociability and distance from their peers combined with an excessive cognitive load of information available only online have taken over the students' concentration, attention, and a clear head. In the context of the pandemic, the socio-cultural approach can help us understand how the causal relationship between social interaction and individual cognitive change has been crucial in explaining certain educational phenomena. The pandemic has forced educators to rethink traditional teaching methods, with a significant shift towards online and hybrid learning environments.

The social context of learning has therefore changed, with learners having to engage with their peers and instructors through online platforms, rather than face-to-face interactions. During the pandemic, the shift to online learning has had a significant impact on students' motivation, participation, and engagement. ZPD can help to explain this phenomenon, as online learning environments may limit the opportunities for learners to receive the necessary support and guidance from their peers and instructors to extend their learning effectively. As a result, students may struggle to remain motivated and engaged, and participation levels may decrease. Overall, the Vygotskian socio-cultural approach and the concept of ZPD can be valuable theoretical lenses to better interpret students' motivation, participation, and engagement during the pandemic. The approach highlights the critical role of social interaction in shaping learning outcomes, and ZPD provides a framework for understanding how learners can extend their existing knowledge and skills with the support of others. Moreover, although the system and the didactic methodologies used were objectively valid, they were not as effective as in a condition of normality and tranquility as seen in the 2018/2019 year.

Moreover, the quantitative analysis conducted on the questionnaires administered to the students revealed two significant aspects. Firstly, the students attempted to compensate for the lack of physical presence by continuously engaging in interactions through the e-learning platform forum. Secondly, the students' emotional state influenced their academic performance.

In summary, the response to the first research question, which aims to investigate the changes in engagement, motivation, and participation in undergraduate mathematics classes with fully distance learning extended for a second year in an emergency, indicates that the emergency situation significantly impacted motivation, participation, and engagement. Specifically, in the academic years 2018/2019 and 2019/2020, the shift from intrinsic to extrinsic motivation was observed due to the external constraint of taking the online course as the only means to gain access to the exam. In 2020/2021, the small number of students who participated in the exam further diminished extrinsic motivation, leading to a significant decrease in participation as the students' emotional state and socialization desires were negatively affected. However, the level of engagement remained acceptable, possibly due to the use of adaptive learning platforms and other technology tools, which allowed the students to feel part of a community.

One plausible reason for this phenomenon occurring is that what Vygotsky (1978) states in his theory of ZDP has failed: the student, situated in a specific educational context, learns through a process of elaboration and integration of multiple perspectives, information, and experiences, offered by confrontation and collaboration with peers or a group of experts. Contact with peers encourages the student to participate more actively in lessons and the educational dialogue; dealing with peers makes the student more self-confident and puts him/her in an emotional and motivational status of disposition towards listening and learning. With COVID-19's second year, all of that came to an end. In addition, it is possible to answer positively to the second research question, namely "Can a custom situation-aware e-learning system and personalized teaching contribute to effective mathematics teaching in terms of competencies acquired by students in this context?"; but it should be noted that this is true not for all students. They did not react the same way to the emergency. Some were emotionally and organizationally prepared for a process of "perspective transformation" and thus were able to perceive the positive aspects of the pedagogical transformation, while others were not. This ties into Mezirow's (1997) theory of transformative pedagogy: according to a psychological dimension, some students experienced anxiety and frustration that negatively affected their academic performance; according to the convictional dimension, they failed to adapt to the new context by abandoning the classic patterns of face-to-face teaching; finally, according to the behavioral dimension, the change in their lifestyle negatively affected their learning process. In contrast, those who succeeded in managing to overcome themselves, their fears and anxieties, accepting and understanding the "new," and becoming individuals more aware of and suited to the uncertainty that characterizes their existence achieved educational success by emphasizing how effective the e-learning platform and personalized teaching methodologies were.

CONCLUSIONS

This paper reports on research conducted by the authors exploring the use of educational technologies, specifically a custom-developed e-learning platform and innovative teaching methodologies, to support learners studying Mathematics in STEM courses. Despite the growing use of technology in university teaching,

many lecturers have preferred traditional chalk-and-blackboard lectures. However, the COVID-19 pandemic and the shift to distance learning have made technologizing teaching indispensable. This research focuses on the effects of distance learning and the virtual environment during the second year of the pandemic, with a particular focus on how motivation, participation, and engagement are impacted. The experiment was conducted in a Calculus II class in the Engineering degree course, with data collected using mixed methods. The qualitative and quantitative data were summarized through three parameters of interest (engagement, participation, and motivation) calculated using an ad hoc FCM map built through a consensus process. During the first year of the pandemic, distance learning also fulfilled a social function, with students creating a network community to discuss and share ideas. However, during the second year, the network community failed to meet the need for face-to-face interaction between students and teachers. The goal of the study was to understand how the use of completely remote teaching for two consecutive years influenced students' participation, engagement, motivation, and awareness.

Distance learning has had a detrimental effect on many aspects of social learning. Students have reported feeling disconnected from the educational community and some have even perceived technology as an obstacle to learning rather than a helpful resource. However, despite these challenges, technology has played a critical role in allowing students to continue their studies. The main findings of this research demonstrate that, over time, distance learning and other social factors can negatively impact students' motivation, engagement, and participation, which can lead to a decrease in mathematical competence and an increase in drop-out rates. However, the authors were able to limit these negative outcomes by modeling their teaching approach to the emergency situation and using an e-learning platform that was sensitive to students' needs. Moving forward, the authors suggest that some of the positive aspects of distance learning that were highly appreciated by students can be integrated with traditional teaching to create a blended modality of didactic action. While technology can support teaching, it cannot fully replace face-to-face interaction. Despite the authors' efforts to optimize education through adaptive technology, external factors have still influenced cognitive processes and partially compromised the effectiveness of the educational activity. The authors hope that by integrating some of the positive aspects of distance learning into traditional face-to-face teaching, they can enhance the overall learning experience for students.

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Ethics declaration: This study involves human participants, human data, and human tissue. The Ethics Committee of the Department of Industrial Engineering at University of Salerno approved this study. The principal investigator declared that the rights, safety, dignity, and wellbeing of research participants were protected.

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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