Improving undergraduate students' performance through a Situation Aware e-learning system

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Abstract

This paper focuses on an adaptive learning system based on the principles of Situation Awareness and Goal Directed Task Analysis to improve students' performance by increasing awareness of their status as defined by the parameters of engagement, motivation, and participation. A technique based on a Fuzzy Cognitive Map (FCM) has been defined to identify the current situation by tracking the learner's behavior and interactions with the system. The FCM drives the feedback generation process to improve the situation awareness of the learner and their motivation, engagement, and participation. The system has been evaluated using the Situation Awareness Global Assessment Technique, involving students during the academic years ranging from 2017 to 2022. The experimental results demonstrate that the system, thanks to the FCM, can significantly improve the situation awareness of the learner, even in an emergency.

Keywords

Fuzzy cognitive map, situation awareness, e-learning

1. Introduction

There has always been a close interdependence between communication and education since the educational activity is a relational and communicative one that takes place between subjects operating in space and time [1]. Sharing space and time between educators and students has been a constant point of reference in education. It is still part of the common feeling that education, in the true sense of the term, should take place through physical presence even if thanks to the network and modern information technologies, educational dialogues and distance learning are possible. In fact, online learning, known as e-learning, refers to the use of multimedia technologies and the Internet to improve the quality of learning by facilitating access to resources and services, as well as remote exchanges and remote collaboration. There are many advantages to preferring online learning to traditional education [2]: the learner no longer has to attend the classroom physically but can connect to e-learning platforms to learn and update at any time of the day and any place. This particular mode of training has proved very useful over time, and its flexibility is often adopted not only by students of all ages but also by companies and professionals, the former to provide training courses for their employees, the latter to attend refresher courses in which they are obliged to participate periodically.

Moreover, they offer high usability of courses, which have no limits of place and time, a high rate of interactivity among learners (communications in forums, open discussions for each course, email), containment of course costs, ease of distribution of teaching materials (including interactive ones, which are often uploaded on the platform or sent by email) and increased personalization of training and learning, designed based on each learner and finally, unlike traditional methods, distance courses are just in time. However, there are some negative aspects to be considered in e-learning. In particular, reference is made to the difficulty of empathic interaction between teacher and learner, drops in concentration, lack of sociability with one's peers, and certainly the difficulty for those who are not very familiar with technology. In fact, even if it seemed that society and the school world were ready for a

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radical technological change, rejecting the old forms of knowledge transmission, and extending learning environments to virtual ones, when the school system was challenged severely during the COVID-19 pandemic period, i.e., when it came to conducting a full-scale test of distance learning, the results were not as hoped for [3].

All over the world, for the entire duration of suspension of teaching activities in the physical venues, Distance-Learning (DL) methods supported by technologies were activated. The problem was inventing a new pedagogy and a new way to organize didactics concretely, since people were deeply impacted at the emotional and affective levels. As a matter of fact, students have experienced moments of strong emotional stress, with the risk of generating a state of frustration and discouraging them from studying. It was not just a question of using technologies in teaching but of 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 a variety of doubts and questions to be addressed; some of them were: An example of bulleted list is as follows.

- What didactic strategies should the teacher adopt to ensure students acquire the same skills as face-to-face teaching?
- How can students' interests be kept alive? How do stimulate them to follow the lessons at a distance?
- Which aspects of face-to-face teaching are compromised with distance learning?

Answering these and other questions was crucial for the teachers to avoid leaving the students adrift in their learning process [4]. Specifically, many students are not uncommon to drop out of their studies due to the first obstacles encountered. 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 dropout, is always more frequent among students who are not sufficiently engaged and motivated with the learning experience [5]. The root causes of students dropping out are a lack of motivation, engagement, and participation [6, 7]. The motivation [8] takes into account the level of interest in the course, the engagement represents the level of involvement in the learning experience [9], whereas participation [10] refers to the action of taking part in activities and projects, the act of sharing in the activities of a group. For these reasons, a modern course cannot be limited to the simple learning content delivery task. Still, it should support the learners in their whole learning experience, leading them to reach their learning objectives successfully. To do so, a learning platform could be used. Still, it should be adaptive, providing each learner with the contents, feedback, suggestions, and experience tailored to her current learning state [11] and not simply being a tool to access training material for self-instruction. As a famous aphorism of Benjamin Franklin says: "Tell me, and I forget, teach me, and I remember, involve me, and I learn". Creating an engaging and interactive virtual environment is necessary to achieve the following benefits: to make the learners more interested in the training, to keep their concentration level high and consequently to achieve the results of the full learning process.

This paper is part of research started in 2017 by the authors on the use of educational technologies, especially through a custom-developed e-learning platform, based on Situation Awareness principles, capable of providing adaptive feedback to students, and innovative teaching methodologies in STEM courses to support learners in their learning process. In previous works, the importance of using educational technologies in the educational dialogue to prevent drop out improves students' engagement, motivation, and participation linked to the Situation Awareness (SA) model, has been highlighted [12, 13, 14]. In the academic year 2017/18, blended teaching was tested using the Just in Time Teaching and Peer-Led Team Learning methodologies integrated with a social platform. In the academic year 2018/19 [15], the experimentation went on using Augmented Reality to address some crucial topics of the mathematics course and evaluating student interaction and participation with Fuzzy Cognitive Maps as a systemic structure model for analyzing critical success factors of the learning system. Augmented Reality has been used to overcome some of these difficulties, using some technological tools (3D glasses, computers, tablets) and innovative methodologies. Furthermore, in the same year, studies were conducted on how the adaptive e-learning platform and its feedback generation system influenced the students' Situation Awareness level. During the academic year 2019/20, during COVID-19 pandemic, the authors [16] analyzed the impact of completely distance learning on student motivation, participation, engagement and performance. Several important findings emerged from this series of work:

- motivation, engagement, and participation are three good indexes for understanding the level of situation awareness of the learner; therefore, they represent a good learner situation model.
- A learner with a high level of SA is more conscious of the current signs of progress, difficulties, and objectives and could make better decisions regarding her learning process. This has beneficial consequences on their performance.

One of the main objectives of this work, in continuity with the previous ones, is to present in detail the e-learning platform that was designed and implemented following the principles of Situation Awareness and Goal Directed Task Analysis (GDTA) [17], how it has evolved to respond to changes in the context (Covid-19 emergency) and the situation model that was used to describe the learner's status.

Situation Awareness Global Assessment Technique (SAGAT) [17] was adopted to assess how the e-learning system has impacted students' awareness of the situation over the years. Since it has been explored previously [12], the relationships with the learner's motivation, engagement, and participation levels. Based on blended learning, after the end of the Covid-19 emergency, the obtained results in the academic year 2021/2022 are compared with those obtained in previous experiments in which the courses were conducted in a blended mode in the academic year 2018/2019 and completely remote in the academic years 2019/2020 and 2020/2021. The comparison was also made in parallel with a group of users who did not use the platform with full functionalities oriented to Situation Awareness to understand the impact of the proposed solution on the students during the years was considered for the experimentation. The data collected seem to show that the use of the e-learning platform developed according to the principles of situation awareness and GDTA allows students to have a greater awareness of what is happening in their learning path than those who used a standard platform. Specifically, these students have a fairly clear idea of their status according to the parameters of engagement motivation and participation; they know how to use it to make decisions, which has beneficial consequences on their performance, as discussed in other authors' works. On the other hand, in the long run, distance learning, in addition to other social factors, has a negative impact on students' situation awareness modeled through motivation, engagement, and participation, despite the countless teaching strategies implemented and the use of an adaptive e-learning platform. This has also negatively affected the level of competencies and has accentuated the drop-out phenomenon, but those aspects will be covered in detail in another work.

2. Background knowledge

2.1. Situation Awareness

Situation Awareness (SA) is a faceted concept encompassing many different elements ranging from cognitive mechanisms and decision-making processes to information processing and human factors. Intuitively, SA means to understand what is happening around us in a specific moment in order to be able to perform a correct action or make a coherent decision with respect to our goal. Consequently, providing a universal definition of SA fitting for different contexts is not an easy task. One of the best definitions is the one provided by Endsley [20]:

"Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future".

In this definition, the three levels which concur to the formation of the SA can be identified: perception, comprehension, and projection. The first level of SA (level 1 SA) is the perception of the status of the elements in the environment. Although it may seem easy to perceive the elements related to a specific task, it can be quite challenging in many application domains just to detect all the necessary data. Moreover, the amount of data often exceeds the operator's ability to perceive it all correctly. The second level to achieve good SA (level 2 SA) is understanding what the data perceived at level 1 means in relation to goals. The data acquired at level 1 are synthesized and aggregated so they can subsequently be assigned a meaning related to the objective to be achieved.

Understanding what the available data means requires good knowledge and a mental model to integrate and interpret the different pieces of information. Level 3 SA means to predict what the perceived elements will do in the future with respect to the goal. In order to have an adequate level 3 of situation awareness it is essential to have a correct understanding of the situation (SA level 2), knowing the system's dynamics and the environment. It is usually quite demanding, as it requires a good understanding of the domain, the situation and a great ability to project the state of many elements into the future. Experience plays an important role in this level because it gives the ability to anticipate future situations and to be proactive with respect to them.

These three levels of Situation Awareness should be placed in the context of dynamic decision-making. Starting from the well-defined and separate situation awareness process, it can be extended to a broader dynamic decision-making model as defined by Endsley herself. The extended model is shown in figure 1. According to this representation, the SA is the operator's internal model of the state of the environment: the operator makes a decision based on what is happening in the environment (i.e. the identified situation) and what he thinks will happen in the near future and then performs the necessary actions. These actions will affect the environment, thus creating a new situation and leading to a new cycle of situation awareness and decision. Beyond this, there is an important distinction to be made, namely that between situational awareness understood as an internal model of the world, i.e., a state of knowledge of what is happening at a given time, and the process of acquiring and maintaining situational awareness by processing and understanding new information. We refer to the process of acquiring situation awareness as situation assessment.

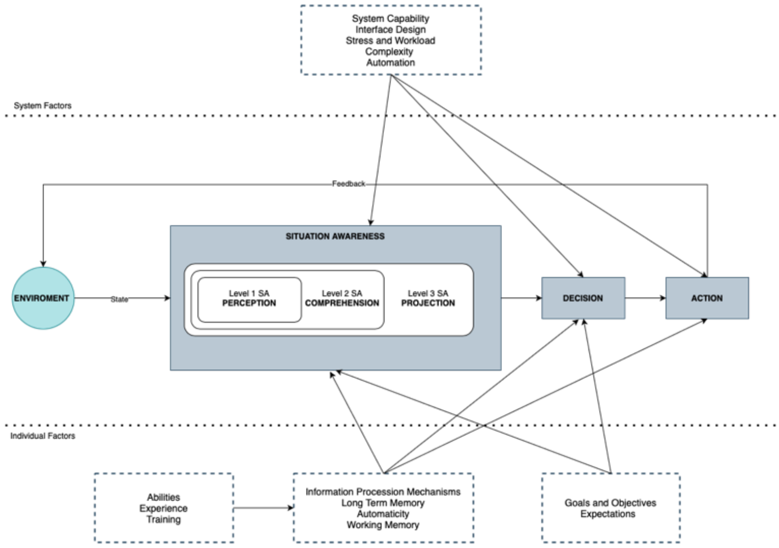

Figure 1. Endsley's Model of Situation Awareness in dynamic decision making

To support the process of SA formation, a proper design of the system and its graphic interface, which explicitly took into account the human factors related to SA, should be needed. This aspect is also fundamental for addressing the SA demons, which are a set of causes that lead to typical errors in SA due to lack of situation awareness. Endsley defined in [19] the eight common causes for lack of SA, called the Demons of Situation Awareness (SA demons). These eight causes are attentional tunneling, data overload, complexity, memory trap, workload and stressors, wrong mental models, misplaced salience, and out-of-the-loop. They occur as a result of individual factors as well as system or environmental factors. Therefore, one of our main goals was to design and implement a system based on Situation Awareness that could improve students and teachers' and teachers' SA levels by softening the issues with SA demons.

2.2. Goal Directed Task Analysis

In some domains, the information an actor has to process to achieve the set objectives is beyond his cognitive capacity. This is due to the high dynamism of the environment in which one operates, which presupposes constant attention on the part of the user, who, therefore, will maintain a high level of awareness with difficulty, thus threatening the achievement of the pre-set objectives. To support SA, Endsley has developed a cognitive task analysis methodology that provides valuable support in system design and promotes situational awareness, thereby improving decision making. This methodology is known as GDTA, or Goal-Directed Task Analysis [17]; according to this technique, goals are a key element from which to determine the key information needed to perform specific tasks and how these should be used and combined to achieve good SA, but not only that, this technique also provides a systematic approach to derive and analyze system requirements based on the goals the user wants to achieve.

Thus, this methodology aims to obtain precise knowledge of the goals that users need to pursue and the decisions to be implemented to achieve these goals.

Identifying goals is key to success for the correct system design, as it offers valuable help in organizing information about it. In fact, this information will be shown to the user taking into account the current goal to be achieved, thus limiting the problem of information overload: in fact, providing only the necessary information at the right time and in the right way, it avoids unnecessary cognitive overload for the user, allowing him to focus only on what matters with respect to the current task.

In order to define the information requirements and complete the decision-making process, the GDTA approach uses different requirement elicitation techniques, such as interviews, ethnographies or the detailed analysis of technical documentation.

The GDTA approach follows several steps, starting by identifying the actors actively involved in the application domain of interest and then defining for each type of actor the goals to be achieved and the most appropriate decisions to achieve them; at the end of these phases, it will be possible to obtain all the information necessary to support the decision-making process.

The GDTA, therefore, consists of three main elements, first of all there are the goals, which represent what the user wants to achieve in the function of a particular task that he has to perform; the goals can be distinguished in overall goal, main goal and sub-goal, the overall goal represents the highest-level goal which the user aims at, to this are associated main goals and sub-goals, preparatory to its achievement.

The general scheme of the goal hierarchy is shown in figure 2, at the top of which is the overall goal, which represents the user's maximum objective in using the platform, to then pass, through successive refinements, to a decomposition of the latter: first into main goals and then, for each of them, into sub-goals.

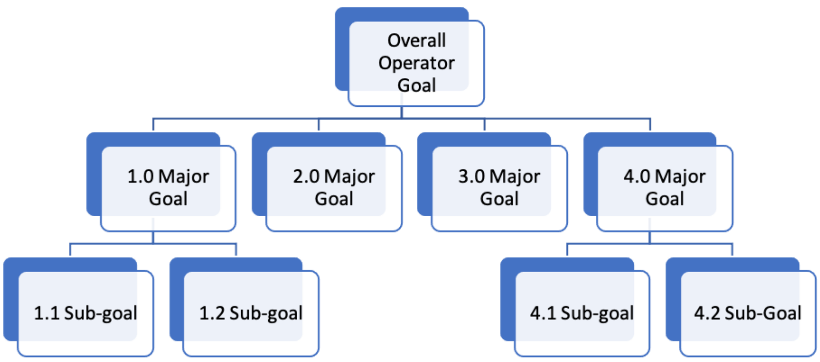

Figure 2: Overview of the goal hierarchy defined through GDTA

2.3. Fuzzy cognitive map

This section describes a soft computing technique for modeling and controlling systems: Fuzzy Cognitive Map (FCM). This technique is one of the core points of our research, in fact it was used for the situation identification technique we defined and implemented in our system. Specifically, parameters related to interaction, participation and motivation, and their causal relationships, have been identified and analysed through a Fuzzy Cognitive Map to describe the student's state during the course. In addition to this analysis purpose, they were also used as a tool for generating feedback to the students to try to maintain an adequate level of student engagement, participation and motivation and thus mitigate the drop-out phenomenon.

A Fuzzy Cognitive Map (FCM), as introduced by Kosko [20], is a symbolic representation based on a fuzzy graph useful for representing causal relationships. It can be used to describe complex systems/environments symbolically, highlighting events, processes and states. An FCM consists of an interconnection of nodes through weighted edges: a graph node is called concept and an edge is called weight. The edge allows for implementing a causal relationship between two concepts, and the weight represents the strength of the influence of the relationship, described with a fuzzy linguistic term (e.g., low, high, very high, etc.).

An FCM can be formalized through a 4-tuple (N, W, A, f), where:

1. $N = \{N_1, N_2, \ldots, N_n\}$ is the set of n concepts which are represented by the nodes of the graph.
2. W: $(N_i, N_j) \rightarrow w_{i,j}$ is a function ($NxN \rightarrow [-1,1]$) which associates the weight $w_{i,j}$ to the edge between the pair of concepts (N_i, N_j).
3. $N_i \rightarrow A_i$ is the activation function which associates to each concept N_i a sequence of activation values, one for each time instant t: $\forall t,\ A_i(t) \in [0,1]$ is the activation value of the concept N_i at time t.
4. $A(0) \in [0,1]$ is the initial activation vector containing the initial values of all the concepts; $A(t) \in [0,1]$ is the state vector at a certain time instant t.
5. f: $R \rightarrow [0,1]$ is a transformation function with a recursive relation $t \geq 0$ between $A(t+1)$ and $A(t)$:

$$\forall i \in \{1, \ldots, n\}, A(t+1) = f\left(\sum_{\substack{i=1 \\ j \neq i}}^{n} w_{ji} A_j(t)\right) \tag{1}$$

Different types of functions can be used as f (x), such as the sigmoid function, the bivalent function or the linear function. FCM can be used to make a what-if inference, starting from a given initial activation vector A(0), to understand what will happen next to the modelled system/environment.

Basically, a Fuzzy Cognitive Map is developed by integrating existing experience and knowledge related to a system. This can be achieved by using a group of experts to describe the structure and behavior of the system under different conditions. With FCM it is usually easy to find which factor needs to be changed and, being dynamic modelling tools, the resolution of the system representation can be increased by applying further mapping. According to Codara [21], FCMs can be used for various purposes, including: underline the behavior of agents, understand the reasons for their decisions and actions taken, highlighting any distortions and limits in their representation of the situation (explanatory function). They can also be useful for predicting future decisions and actions (forecasting function) and for helping decision-makers reflect on a given situation's representation (reflexive function).

Several applications of fuzzy cognitive maps in different domains, such as control, multiagent systems, dynamical characteristics, learning procedures, etc., are realized to improve these systems' performance [22]. The main reasons why FCMs are used are: easy to build and parameterize, easy to use, flexible in representation, easily understandable even to non-expert users, convenient for managing complex problems related to the processing and management of knowledge in a structured way, convenient for managing the feedback structure of the modelled system with dynamic effects.

3. Situation identification model

One of the cornerstones of our research work is the analysis of the student's current status to support her in her educational journey in the best possible way, preventing her from dropping out of the courses and achieving her educational goals. In order to do this, it is necessary to be able to describe the state the student is in formally. For this purpose, we used the theory of situation awareness, presented in section 2.1, to define the student's status in the three high-level concepts of engagement, motivation, and participation. The motivation [8] takes into account the level of interest in the course, the engagement represents the level of involvement in the learning experience [9, 23], whereas participation [10] refers to the action of taking part in activities and projects, the act of sharing in the activities of a group. An in-depth discussion of these parameters and why they have been chosen to describe the student's status can be found in the authors' previous works [13, 24]. This section describes in detail the situation awareness technique we defined and implemented based on a Fuzzy Cognitive Map (FCM). The objective of the FCM is to consider all the effects that the variables identified in the Status Model have on the learner's engagement, motivation, and participation, which are the three high-level concepts representing the learner's current status.

Before choosing FCMs, an in-depth study of the scientific literature was conducted, evaluating the different fuzz-type intelligence computing approaches proposed by the community to represent the situation model (like, for instance, Fuzzy Inference Systems with if-then rules). With respect to other fuzzy approaches, the use of FCM provides us with these advantages:

- FCMs are based on causal cognitive mapping, which provides an efficient way to elicit and capture the knowledge of the experts of the domain and provide an intuitive way to represent such knowledge which can be easily managed and updated by such experts Kokar and Endsley [25];
- maps can be based on interviews, text analysis or group discussions and can be easily modified or extended by adding new concepts and/or relations or changing the weights assigned to causal links Kosko [18], Kokar and Endsley [25];
- FCMs have been extensively used as a way to support situation identification and decision making, helping decision-makers in gaining a better understanding of the domain of the situation and improving their mental models Jung and Lee [26];
- traditional FIS could require many rules to represent complex relations, especially when a high number of inputs needs to be considered Abeer and Miri [27].

The designed FCM, shown in Fig. 3, resulted from a consensus process in which a team of four education experts worked. Each expert, starting from the status model we have defined, has proposed her FCM to identify the causal relationships and weights between the available concepts, such as a process described in [26]. The weights are represented by seven linguistic terms: no impact = 0.00, very low = 0.165, low = 0.335, medium = 0.50, almost high = 0.665, high = 0.835, very high = 1.00. Then, we aggregate the different maps proposed by the experts to obtain one FCM. When some differences arise between the relationships and weights proposed by the experts, we asked them to discuss these differences and try to find an agreement until they achieve a sufficient degree of consensus.

The FCM can be considered as organized in different layers. The low layer contains the concepts of the FCM representing the variables discussed in [13, 24], which are partially listed in Fig. 3 for legibility reasons. The activation levels of these "leaves" concepts represent the value of each variable. When the value of these variables changes (due to the actions performed by the student), the other concepts of the FCM are influenced according to the causal relationships between them. The middle layer contains the concepts composing the engagement-motivation (Interaction, Assignment and Forum Activities) and participation (Emotion, Social Activity).

The final layer contains the concepts of Engagement, Motivation, and Participation representing the current learner status. These concepts are influenced directly by the concepts of the middle layer and indirectly by the concepts of the low layer.

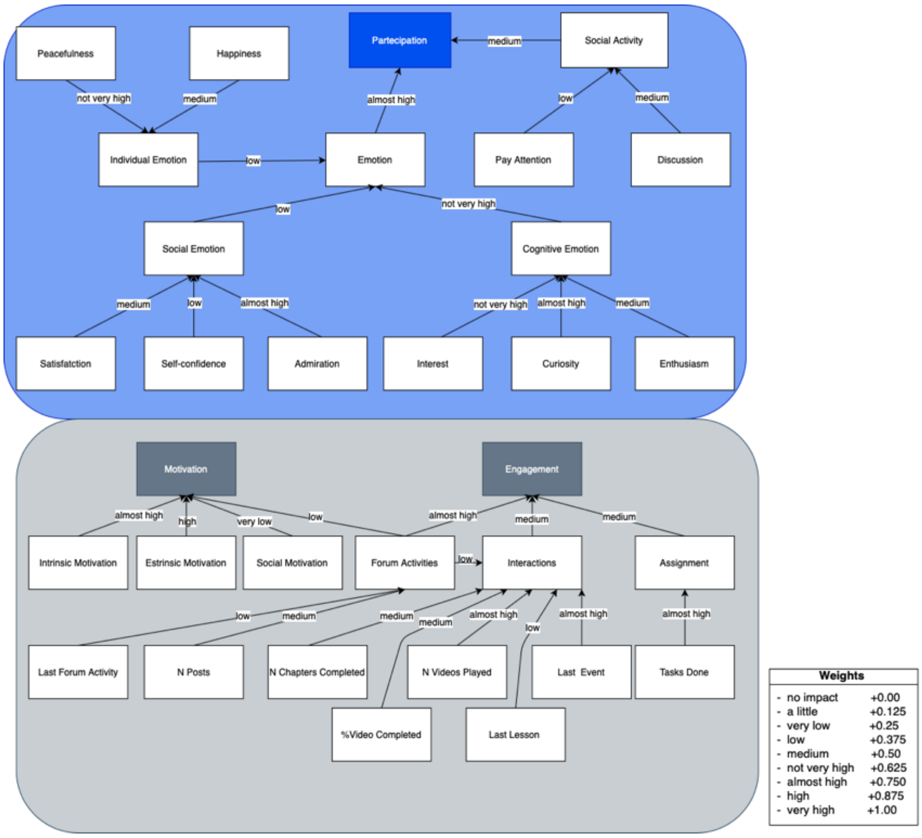

Figure 1. Fuzzy Cognitive Map for situation identification

4. Situation-aware e-learning system

This project aims to adopt a motivational approach to support learning by creating an engaging experience to reduce student dropouts. The main objective of this section is to present the e-learning system we have worked on both in its design and development during the Research & Development Project "MOLIERE". The system has been developed following the best design practices and principles of Situation Awareness Theory [17] and exploiting the domain experts' knowledge (teachers and educators). The overall design process that was adopted is shown in figure 4.

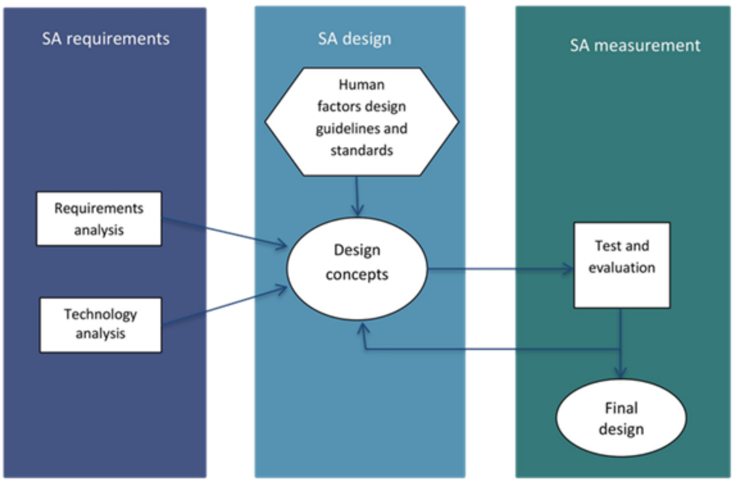

Figure 4. The three phases of the design process of a system based on Situation Awareness

The first step (SA requirements) involved studying the systems, techniques and approaches of SA, which was useful in outlining the main areas of research in computer science in situational awareness, to understand what are the most common categories of approaches that scholars and researchers usually adopt to overcome the errors and demons of SA [19]. Thus, the most promising works were categorized according to the underlying technique or approach they proposed or adopted (e.g., data mining, logic and formal theory, machine learning, computational intelligence, etc.). Furthermore, considering the functional view of the SA system, it was possible to classify each of the research areas identified in SA with respect to its most adopted system functionalities. After this initial study, the appropriate techniques and methodologies functional to the proposed system were chosen. Furthermore, GDTA approach in this phase allowed a clear classification of the objectives the user should achieve; it started by defining the high-level overall objectives, and then identified the related lower-level objectives. The teacher, for example, has the general aim of making the learning experience productive, and to achieve this objective, she will necessarily have to pursue other lower-level objectives, such as: carefully planning the training course, involving the course participants in each phase, constantly monitoring the results, etc. In the same way, the hierarchy of the student's goals is defined. The student's overall goal is to successfully acquire the end-of-course certificate by passing the exam but to achieve this goal she will have to: acquire all the course content, interact with the learning environment, constantly monitor her learning path, etc.

Then, the development of the system was carried out according to the different stages of the Endsley model, taking into account the opinion of domain experts and the users' goals previously identified (SA design). Some preliminary evaluations were necessary in order to understand if the chosen methodologies were compatible, giving good comfort (SA measurement). In fact, some modifications and improvements were made with respect to the first version of the system [16] in order to better respond to the users' needs during the Covid-19 emergency period.

In order to better present the main features of this system, reference should be made to figure 5 in which the final conceptual architecture of the system is sketched.

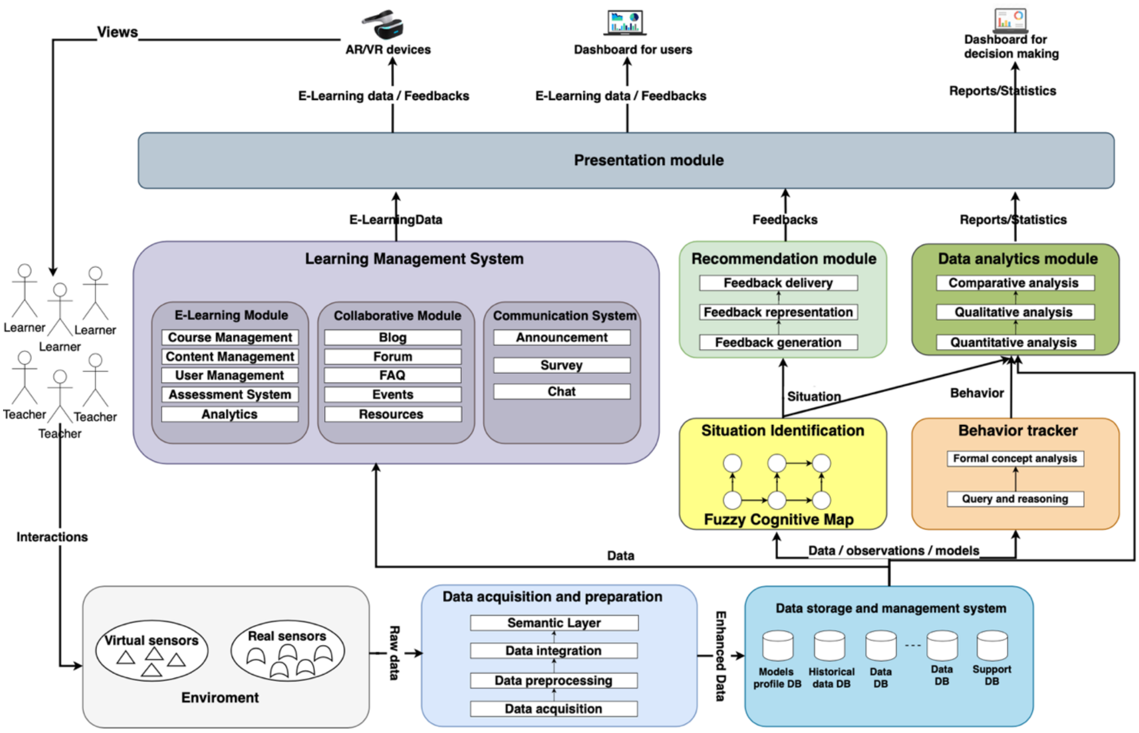

Figure 5. Conceptual architecture of situation aware learning system

The architecture was organized into tiered subsystems; from bottom to top, we have: i) Data acquisition and preparation; ii) Data storage and management system; iii) Behaviour tracker; iv) Situation identification module v) Learning Management system; vi) Recommendation module; vii) Data analytics module viii) Presentation module.

At the lowest level of the system, directly in contact with the users, there are both real and virtual sensors to record students' interactions with the e-learning platform and to monitor their facial expressions used to identify the situation. Data acquisition and preparation deal with acquiring the raw data provided by the sensors and analyzing and organizing them. Such data could then be elaborated through some integration techniques and semantically enriched before being transferred to the Data storage and management system. In this way, it is possible to generate new knowledge from the aggregated data that is not evident from the individual data. Data storage and management system includes relational databases and triple stores capable of storing the data and models that are used by all the higher-level subsystems, which are: the Learning Management System (LMS), Situation Identification Module, and the Behavior tracker.

The LMS, divided into E-Learning module, Collaborative Module and Communication System, includes the modules necessary for the classic services of an e-learning system such as Course Management, User Management, Blog, Forum, Chat, etc. Situation Identification Module is certainly one of the most important modules of the system because it allows, through the use of the Fuzzy Cognitive Map, the identification of the student's status in terms of motivation, engagement and participation useful both to generate feedback and to provide the basis of information for in-depth analysis by teachers in order to make important decisions, for example about the organization of the course and teaching content. Whereas, the Behavior Tracker subsystem acquires data, observations and models which are examined and processed in order to produce useful knowledge to derive user behavior, through Formal Concept Analysis (FCA) processes and reasoning on semantic models. Specifically, it is useful for extracting some behavioral patterns to identify dropout risks. To limit drop-out, the recommendation module produces and forwards adaptive and personalized feedback to students to help them maintain adequate levels of engagement, motivation and participation. The modules of this subsystem are Feedback Generation, Feedback Representation and Feedback Delivery. The feedback generation module generates feedback based on the learner's current situation identified by the situation identification module with FCM. The process of feedback generation has been discussed in detail in one of the authors' papers [26, 27] but it is considered appropriate to point out what changes have been implemented in this module to better cope with the emergency situation during the Covid-19 period. The main motivation behind the changes that were made to this module are described in authors' paper [12], which reports on the analysis of the students' situation in terms of engagement, motivation and participation during the first year of lockdown. Specifically, what was observed in that period was a clear decline in student participation due mainly to the lack of attention and frustration caused by the impossibility of living a normal life. This could lead to a wide dropout. Therefore, it was considered necessary to act mainly by sending personalized feedback related to the participation parameter, through the Cognitive Emotion-Individual Emotion-Social Activity values, if this was below a threshold. Otherwise, the generation process remains linked to the Engagement and Motivation parameters, as done in the past. Another important change was to make the presence of the professor marginal in the selection phase of the feedback, mainly of supervision, covering this role with an expert system able to make the choice autonomously. It was considered appropriate to act in this way to lighten the cognitive load of the professor during a period of enormous stress. The new feedback generation and selection process is shown in figure 6.

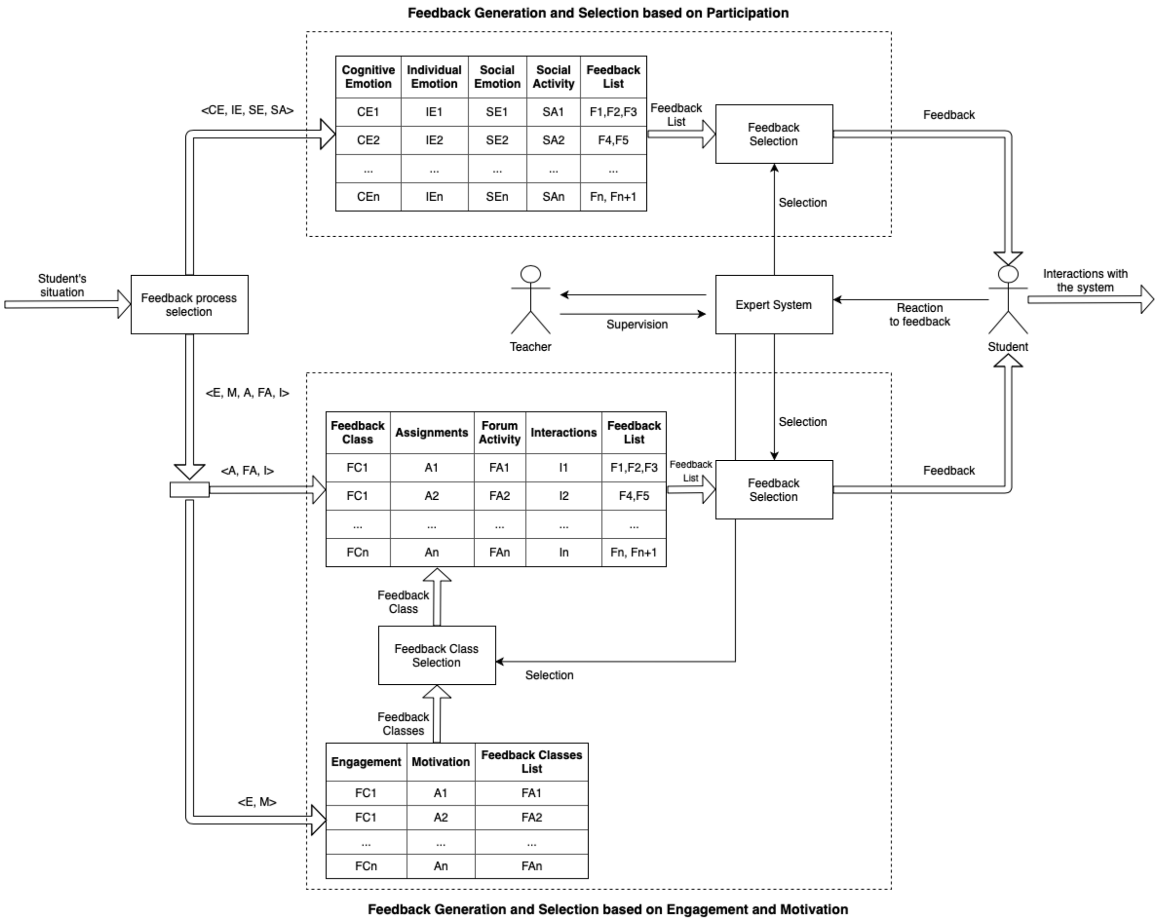

Figure 6. The new feedback generation and selection process

Whereas, the Feedback representation module has the task of visually constructing the feedback based on the target device, for example by appropriately choosing icons, colours, and text to enhance its meaning and to facilitate the understanding. The third module, Feedback delivery, has the function of transferring the feedback generated to the Presentation module, towards the device of the user (e.g., a mobile device, an augmented reality device, or a classic PC).

At high level, decision making requires appropriate and representative information and data to be analyzed. Typically, more effective decisions can be made using a meaningful set of data, which has an appropriate amount of information with respect to the intended goal. Data analytics module combines data entry and manipulation capabilities with report production, graphical display and statistical analysis facilities. The student's status and behavior, cross-referenced with lower-level data such as answers to questionnaires, are used by this module. We have massively exploited this module during the experimentation phases of our scientific work. The Presentation module is the subsystem that deals with the display of information to users according to the models and principles of Situation Awareness and Goal-Directed Task Analysis [17]. This module includes views for student and teacher dashboards, which can be displayed according to the device used.

5. Evaluation

In the evaluations that have been done in other works of the authors [13, 14, 15, 16], it has been verified that the situation identification technique, used in the process of feedback generation and based on the Fuzzy Cognitive Map, is useful to increase the level of situation awareness (SA) of the learner. Furthermore, it has been noticed that a learner with a high level of SA is more aware of current signs of progress, difficulties, and goals and can make better decisions about his learning process and achieve better results. Furthermore, it was verified that the level of motivation, engagement, and participation are three good indices to understand the level of the learner's situation awareness and therefore represent a good model of the learner's situation. So, the purpose of the evaluation of this paper is to assess for four academic years, i.e., from 2018/2019 to 2021/2022, the impact of the proposed e-learning platform on students' Situation Awareness, comparing the results with those obtained from the use of a standard platform not oriented to Situation Awareness.

5.1. Method

The experimentation involved the Calculus II students in the first year of Mechanical Engineering and Management Engineering at the University of Salerno. The experimentation results are obtained by comparing the collected data in the academic years 2018/2019, 2019/2020, 2020/2021, and 2021/2022. It should be noted that in the academic years 2018/2019 and 2021/2022 it has been used a, blended learning (students attended classroom lessons and used the reference e-learning platform as an integration), whereas in the academic years 2019/2020 and 2020/2021, a full distance learning was used (students followed the course completely online). After the first year of distance learning in which professors suddenly had to change their teaching due to the sudden closure of the university due to the pandemic, classes in the 2020/2021 academic year were also conducted completely online. During 2019/2020, one of the teacher's challenges was quickly adapting the didactic content plan with completely remote teaching. In order to motivate students, encourage participation and engagement, keep students' degree of attention alive, and stimulate their epistemic curiosity, interest, optimism, and passion, it was necessary to readjust the disciplinary methodological knowledge and teaching contents through the use of the proposed e-learning platform. Teachers and students were left disoriented due to the extended pandemic emergency and still forced into completely distance learning for the second year in a row. Once again, teachers were faced with the challenge of maintaining high levels of engagement, motivation, and participation, thus promoting students' educational success. In fact, students during the first year of the pandemic have accepted, even with difficulty, completely distance learning as a means to ensure their education.

The four classes, one per year, in which the experimentation was conducted were made up of 131, 112, 98, and 104 students, respectively. Cochran's formula was used to calculate the sample size for the experimentation:

$$n_0 = \frac{Z^2pq}{e^2} \qquad (2)$$

Where: e is the desired level of precision (i.e., the margin of error); p is the (estimated) proportion of the population with the attribute in question; q is 1 – p; the z-value is found in a Z table. It is s the abscissa of the normal curve cuts off an area α at the tails (1 - α equals the desired confidence level, e.g., 95%); n0 is the sample size.

In our experimentation the chosen parameters were: {Z = 1.65; p = 0.75; e = 0.15} that led to a sample of 30 people.

In order to conduct the experimentation, the SAGAT methodology was adopted [17]. Specifically, it was useful to assess how the proposed e-learning system impacted the student's situation awareness over the years. SAGAT relies on the knowledge of domain experts to develop a questionnaire to assess the users' level of situation awareness. The user is involved in simulations of one or more realistic scenarios with the implemented system. At some point, the simulation freezes, according to SAGAT guidelines, and a series of questions are asked to the user to probe SA. The questions are chosen to assess the degree of awareness in the three levels of perception, comprehension, and projection. The two scenarios identified in the first authors' experimentation [16] were re-used in order to perform a comparative analysis with previous years. These scenarios were simulated using the adaptive learning system. The participants in this experiment were students who would have to figure out what the next activity should be to improve their learning processes and achieve their learning goals. The questions asked to assess perception (Level 1 SA) in the two scenarios are related to identifying specific items or parameters. For example, the student should identify the completion percentage of course activities. To test level 2 SA (comprehension), questions were asked about the student's status to be assessed through the activities performed and the results obtained. Finally, for Level 3 SA (projection), the questions ask what action should be taken: the student should choose the next activity. Each scenario was run two times in random order to test two different system modes. In the first mode, the system does not have the situation-aware elements such as feedback, i.e., It lacks the notification section and the widget with the list of received feedback; in the second, it has full functionality developed following situation awareness principles; for example, it provides students with feedback using the FCM approach. In this way, by comparing the difference in the percentage of correct answers given by the participants, it was possible to understand whether the proposed system is useful for increasing situation awareness, even in a changing environment such as that experienced during the Covid-19 pandemic.

5.2. Results and discussion

This subsection reports the results, specifying the percentage of correct answers the evaluation participants gave using the SAGAT methodology. Specifically, Figure 6 shows the levels of Situation Awareness of the users obtained in the four years ranging from the academic year 2018/2019 to the academic year 2021/2022, considering both scenarios and compared with each other. This comparison was made considering that for the years 2020/2021 and 2021/2022, the results obtained by users who used the system with feedback in the updated version were used in contrast with the other two years in which the previous version of the system was used. The figure shows the average rate of correct answers given by participants.

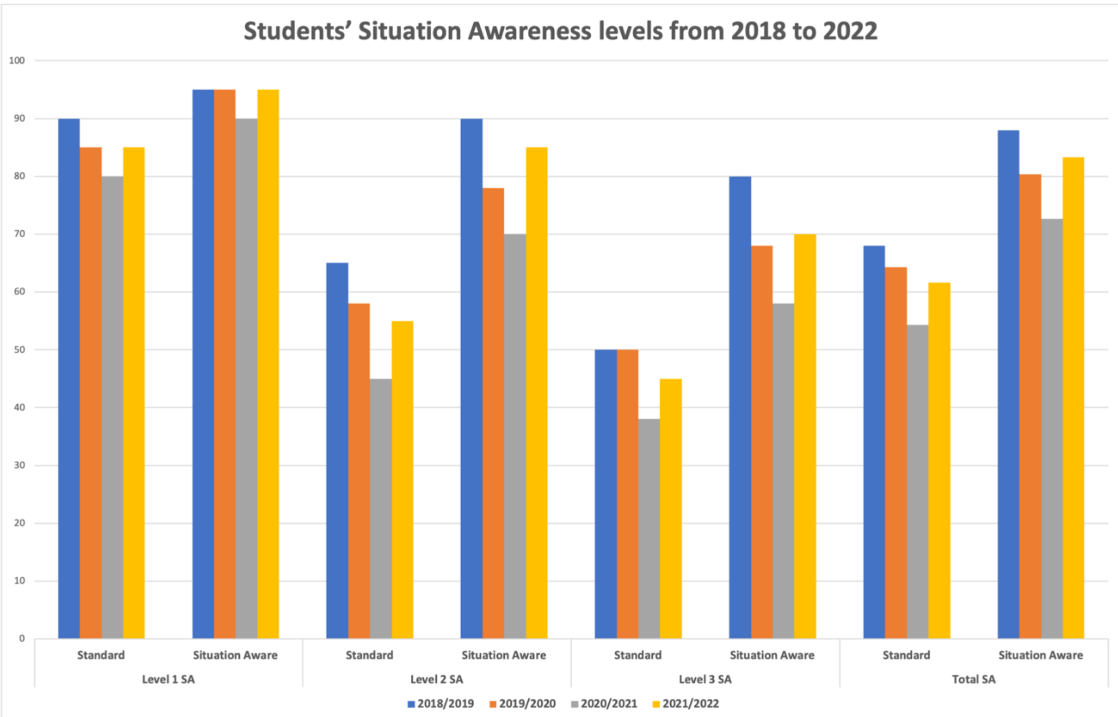

Figure 7. Comparative results of SAGAT evaluation for academic years 2018/2019, 2019/2020, 2020/2021, and 2021/2022

In detail, the results obtained from comparing the levels of Situation Awareness recorded in the four years under observation are shown in Figure 6 (in blue 2018/2019, in orange 2019/2020, in grey 2019/2020, and yellow 2021/2022), reveal how they went down during the two years of Covid-19 pandemic both for users who used the system in a standard version and for users who used the system with full functionalities. Situation Awareness values in all three levels (level 1-perception, level 2-comprehension, level 3-projection) and overall peaked in the 2018/2019 year when teaching was held in person. The first significant decay occurs in 2019/2020, i.e., the first of completely distance teaching due to the emergence of Covid-19. The declining trend is also confirmed in 2020/2021, which seems roughly linear. On the one hand, there is a certain amount of gratification because the updated system has been able to contrast the inexorable decline in the levels of Situation Awareness. The changes made have made it possible to obtain, in the second consecutive year of completely distance learning, a total level of SA equal to 72%, which is acceptable if we consider that under the same conditions, the system without SA elements went down to 54%.

On the other hand, there is a good deal of concern because, despite the efforts made and the targeted changes implemented according to the principles of Situation Awareness design, the values in the three levels still decreased. One plausible reason for this phenomenon is that 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 colleagues combined with an exaggerated cognitive load of online information have taken over the students' concentration, attention, and a clear head. Although the system was objectively valid, it was not as effective as in a condition of normality and tranquility as seen in the 2018/2019 year. An encouraging revival occurred in the 2021/2022 academic year when lectures returned to face-to-face mode. The platform was a complementary tool to teach. In fact, the results obtained are high and comparable with those of the 2018/2019 year, which is the best one among the fourth years analyzed: the return to normality, the reduction of the cognitive load, and above all, the regain in social interaction have played a fundamental role.

Finally, two of the most important results of this research are:

- the use of the e-learning platform developed according to the principles of situation awareness and GDTA allows students to have a greater awareness of what is happening in their learning path than those who used a standard platform. Specifically, these students have a fairly clear idea of their status according to the parameters of engagement motivation and participation; they know how to use it to make decisions, which has beneficial consequences on their performance, as discussed in other authors' works.
- Technologies are a tool to support teaching action but cannot completely replace the social action of face-to-face teaching. Although teaching activities have been remodeled and technologies have been used adaptively to optimize teaching, cognitive processes have been influenced by external factors that have partly compromised the effectiveness of the educational action. The authors hope that some aspects appreciated by the students can be integrated with traditional face-to-face teaching in the future.

6. Conclusions

An adaptive e-learning system based on situation awareness has been discussed. The system has been designed and developed according to the design principles of SA and GDTA. To improve the awareness of the students' defined through their motivation, engagement, and participation levels, adaptive feedback is sent to learners. The feedback selection process is driven by a Fuzzy Cognitive Map, implemented to identify the learner's situation by analyzing her activities on the platform. Furthermore, this work conducted a comparative analysis of the Situation Awareness of undergraduate students in the academic years 2018/2019, 2019/2020, 2020/2021 and 2021/2022. In 2018/2019 and 2021/2022, a blended type of teaching was adopted (in-person lectures and support of supplementary activities through an e-learning platform), while in the other two years, a completely distance teaching due to the COVID-19 pandemic. In the context of the emergency of COVID-19, students have experienced moments of strong emotional stress, with the risk of generating a state of frustration and discouraging them from studying. The use of the proposed adaptive e-learning system based on situation awareness and remodeled teaching has been essential in limiting this phenomenon. The experimentation was conducted using the SAGAT methodology, involving students participating in classes during the courses held over the past four years. The results show that the situation identification technique and the situation model can increase the level of situation awareness of the students, even in an emergency.

On the other hand, however, there has been a significant decline in Situation Awareness in pandemic years due to the marked presence of some of the eight demons identified by Endsley: the anxieties, stress, lack of leading a normal life emphasized by the absence of sociability and distance from their colleagues combined with an exaggerated cognitive load of information available only online have taken over the concentration, attention and clear head of the students. Technologies are a tool to support teaching action but cannot completely replace the social action of face-to-face teaching. Although teaching activities have been remodeled and technologies have been used in an adaptive way to optimize teaching, cognitive processes have been influenced by external factors that have partly compromised the effectiveness of the educational action. This work is part of research conducted by the authors over the years; other findings related to the impact of the e-learning platform on engagement, motivation, participation, drop-out, and students' skills will be reported in other works.

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8. References

[1] Nichols, M. (2003). A theory for eLearning. Journal of Educational Technology & Society, 6(2), 1-10.

[2] Cross, J. (2004). An informal history of eLearning. *On the Horizon*, *12*(3), 103-110.

[3] Müller, A. M., Goh, C., Lim, L. Z., & Gao, X. (2021). Covid-19 emergency elearning and beyond: experiences and perspectives of university educators. *Education Sciences*, *11*(1), 19.

[4] M Alhumaid, K., Ali, S., Waheed, A., Zahid, E., & Habes, M. (2020). COVID-19 & Elearning: Perceptions & Attitudes Of Teachers Towards E-Learning Acceptancein The Developing Countries. Multicultural Education, 6(2), 100-115.

[5] Y. Levy, "Comparing dropouts and persistence in e-Learning courses", Computers & Education. 48. 185-204, 2007.

[6] J. Keller, K. Suzuki, "Learner motivation and E-learning design: A multinationally validated process", Learning, Media and Technology. 29. 229-239, 2004.

[7] R. Carini, G. Kuh, S. Klein, "Student Engagement and Student Learning: Testing the Linkages", Research in Higher Education. 47. 1-32, 2006.

[8] Lepper, M. R. (1988). Motivational considerations in the study of instruction. *Cognition and Instruction, 5*(4), 289–309.

[9] Kuh, G. D. (2003). What were learning about student engagement from NSSE: Benchmarks for effective educational practices. Change: The Magazine of Higher Learning, 35(2), 24–32.

[10] Dominguez, R. G. (2012). Participatory learning. *Encyclopedia of the Sciences of Learning,* 2556–2560.

[11] F. Gasparetti, A. Micarelli, G. Sansonetti, "Exploiting web browsing activities for user needs identification" in Proceedings - 2014 Int Conf on Computational Science and Computational Intelligence, pp. 86-89, 2014.

[12] Capone, R., & Lepore, M. (2021). From Distance Learning to Integrated Digital Learning: A Fuzzy Cognitive Analysis Focused on Engagement, Motivation, and Participation During COVID-19 Pandemic. *Technology, Knowledge and Learning*, 1-31.

[13] Capone, R., & Lepore, M. (2020). Augmented Reality to Increase Interaction and Participation: A Case Study of Undergraduate Students in Mathematics Class. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 185-204). Springer, Cham.

[14] D'Aniello, G., De Falco, M., Gaeta, M., & Lepore, M. (2020). A situation-aware learning system based on fuzzy cognitive maps to increase learner motivation and engagement. In: *Proceedings of the 2020* IEEE International Conference on Fuzzy Systems (FUZZ-IEEE) (pp. 1–8).

[15] Capone, R. (2022). Blended Learning and Student-centered Active Learning Environment: a Case Study with STEM Undergraduate Students. *Can. J. Sci. Math. Techn. Educ.* **22,** 210–236 https://doi.org/10.1007/s42330-022-00195-5
[16] Branchetti, L., Capone, R., & Rossi, M. L. (2021). Distance – Learning Goes Viral: Redefining the Teaching Boundaries in the Transformative Pedagogy Perspective. *Journal of E-Learning and Knowledge Society*, *17*(2), 32-44. https://doi.org/10.20368/1971-8829/1135418
[17] M. Endsley, "Designing for situation awareness: An approach to user- centered design", CRC press, 2016.
[18] M.Endsley,"Toward a theory of situation awareness in dynamic systems: Situation awareness", Human factors. 37. 32-64, 1995.
[19] M.R.Endsley, "A taxonomy of situation awareness errors," Human factors in aviation operations,vol.3,no.2,pp.287–292,1995.
[20] B.Kosko,"Fuzzy cognitive maps,"International journal of man-machine studies, vol. 24, no. 1, pp. 65–75, 1986.
[21] Codara, L. (1998). Le mappe cognitive: uno strumento di analisi per la ricerca sociale e per l'intervento organizzativo. Carocci
[22] Aguilar, J. (2005). A survey about fuzzy cognitive maps papers. *International journal of computational cognition*, *3*(2), 27-33.
[23] Y. Xiong, H. Li, M. Kornhaber, H. K. Suen, B. Pursel, D. Goins, , "Examining the Relations among Student Motivation, Engagement, and Retention in a MOOC: A Structural Equation Modeling Approach". Global Education Review. 2. 23-33, 2015.
[24] D'Aniello, G., de Falco, M., Gaeta, M., & Lepore, M. (2020). Feedback generation using Fuzzy Cognitive Maps to reduce dropout in situation-aware e-Learning systems. In *2020 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA)* (pp. 195-199). IEEE.
[25] M. M. Kokar and M. R. Endsley, "Situation Awareness and Cognitive Modeling," in *IEEE Intelligent Systems*, vol. 27, no. 3, pp. 91-96, 2012.
[26] Jung, Y., & Lee, J. (2018). Learning engagement and persistence in massive open online courses (MOOCS). Computers and Education, 122, 9–2
[27] Abeer, W., & Miri, B. (2014). Students' preferences and views about learning in a MOOC. *Procedia-Social and Behavioral Sciences*, *152*, 318-323.
[28] D'Aniello, G., Gaeta, M., Lepore, M., & Perone, M. (2021). Knowledge-driven fuzzy consensus model for team formation. *Expert Systems with Applications*, *184*, 115522.
[29] Lepore, M., & Petruzziello, A. (2021). zA Situation-Aware DSS to Support Assisted Reproductive Technology Outcome Prediction. In *2021 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA)*(pp. 103-107). IEEE.