Sumerianz Journal of Education, Linguistics and Literature, 2020, Vol. 3, No. 8, pp. 178-185
ISSN(e): 2617-1201, ISSN(p): 2617-1732
Website: https://www.sumerianz.com

Original Article Open Access

Traditional and Artificial Learning Theories and Teaching Methods

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Article History
Received: July 7, 2020
Revised: August 2, 2020
Accepted: August 10, 2020
Published: August 11, 2020

Abstract

The present article studies the main traditional learning theories and teaching methods and compares them to the recently developed with the help of computers and Artificial Intelligence (AI) teaching and learning methods. Innovative teaching techniques are examined like the 5E's procedure, the APOS/ACE insdtructional treatment of mathematics, flipped learning, etc. Also machine learning methods are studied like the smart learning systems using ontological engineering and case-based reasoning as authoring shells, the use of social robots in future education, etc. The new role of the teacher in a modern classroom and other perspectives of future research on artificial teaching and learning approaches are also discussed.
Keywords: Behaviorism; Cognitivism, constructivism; 5E's teaching method; APOS/ACE instructional treatment of mathematics; Flipped learning; Artificial intelligence (AI); Smart learning systems; Ontological engineering; Case-based reasoning (CBR); Social robots.

1. Introduction

Learning is one of the fundamental components of the human cognitive action. In psychology and education it refers to a process that combines cognitive, emotional, and environmental influences for acquiring or enhancing one's knowledge and skills. Volumes of research have been written about learning and many theories and models have been developed by the specialists for the description of its mechanisms.

The role of teaching is to promote the learning of the corresponding subject. However, while theory provides means for analyzing learning, the process of teaching remains to a great part theoretically unsupported. In fact, theories help to analyze and explain, but they rarely provide direct guidance for practice. The present article aims at studying the main traditional learning theories and teaching methods and at comparing them to the recently developed with the help of computers and *Artificial Intelligence (AI)* teaching and learning methods. *Artificial Learning* in this work is understood to be any kind of learning acquired by using methods and techniques of AI.

The rest of the article is organized as follows: In Section 2 the main traditional learning theories and teaching methods are examined. Section 3 studies the role of computers as auxiliary tools in Education and the teaching models that have been developed with their help. Smart learning systems and other recent applications of AI to education are presented in Section 4, while Section 5 compares the traditional with the artificial teaching and learning methods. The article closes with the final conclusions and a brief discussion on the perspectives of future research for artificial learning and teaching methods and techniques. .

2. Traditional Learning Theories and Teaching Methods

There are three main philosophical frameworks under which the contemporary learning theories fall:

- *Behaviorism*, a theory established by the American psychologist John B. Watson (1878–1958), which considers learning as the acquisition of new behavior based on environmental conditions and discounts any independent activities of the mind (Cherry, 2019).
- *Cognitivism*, which replaced behaviorism during the 1960′s as the dominant theory for the process of learning and argues that knowledge can be seen as a process of symbolic mental constructions and that learning is defined as change in individual's cognitive structures (Wallace *et al.*, 2007). More explicitly, the learning process involves representation of the stimulus input, i.e., use of the contents of one's memory to find the suitable input information, interpretation of the input data to produce the new knowledge, generalization of this knowledge to a variety of situations and categorization of it in the already existing learner's cognitive schemata. In this way the individual becomes able to retrieve, when necessary, the new information from his/her proper cognitive schema and to use it for solving related problems. Changes in the learner's behavior are in fact observed, but only as an indication of what is occurring in his/her mind. In other words, cognitive theories look beyond behavior to explain the brain-based process of learning.
- *Constructivism*, a philosophical framework based on Piaget's theory for learning and formally introduced by von Clasersfeld during the 1970s, which suggests that knowledge is not passively received from the environment, but is actively constructed by the learner through a process of adaptation based on and

constantly modified by the learner's experience of the world (Taber, 2011). This framework is usually referred as *cognitive constructivism.* The synthesis of the ideas of constructivism with Vygosky's social development theory (Crawford, 1996) created the issue of *social constructivism* (McKinley, 2015). According to Vygosky, learning takes place within some socio-cultural setting. Shared meanings are formed through negotiation in the learning environment, leading to the development of common knowledge. The basic difference between cognitive and social constructivism is that the former argues that thinking precedes language, whereas the latter supports the exactly inverse approach.

Some decades ago, the dominant teaching method in school education used to be the *explicit instruction (EI)*, which is mainly based on principles of cognitivism. The teacher is in the "center" of this method and tries with clear statements and explanations of the mathematical context and by supported practice to transfer the new knowledge to students in the best possible way (Doabler and Fien, 2013). The main criticism against EI is that it may prevent conceptual understanding and critical analysis (Smith *et al.*, 2016). Therefore, many teachers, adopting ideas of constructivism, enriched the EI with a series of challenging questions so that to keep an active discourse with students, as a means to promote critical thinking (Kinard, 2008).

However, constructivism and the socio-cultural theories for learning have become very popular during the last decades as a basis for teaching and learning, especially among teachers of the elementary and secondary education. New teaching approaches have been introduced, like the *problem-based learning* (Voskoglou, 2010), the *application-oriented teaching* involving mathematical modeling (Voskoglou, 2005), the *inquiry-based learning* through creative exploration (Jaworski, 2006), the formation of *Communities of Practice (CoPs)* among students and teachers (Voskoglou, 2019a), etc.

A typical teaching method developed according those lines is the *"5 E's" instructional treatment*. The acronym "5 E's" is due to the five successive phases of that treatment including engagement, exploration, explanation, elaboration and evaluation (Voskoglou, 2019b). The "5E's" method promotes the fruitful interaction among students and teachers and facilitates the production of the new knowledge on the basis of prior knowledge and experiences.

Much progress has been made in the last 20 years on analyzing the processes by which students come to understand mathematical ideas (*mathematical cognition*) and how numeracy is acquired (*numerical cognition*). Experimental psychology, neuroimaging, and single cell recording experiments have converged to identify how these basic skills are used to support the acquisition and use of abstract mathematical concepts (Gallistel, 2005). Predictive mathematical models are used nowadays to better understand how humans conceptualize information. For example, in (Martinez-Garcia *et al.*, 2019) a model is presented that mimics pre-learned patterns of behavior through fractional differential equations.

3. Computers as Auxiliary Tools in Education

Computers have become in our days a valuable tool for Education providing through the web a wealth of information for teachers and learners. The animation of figures and of mathematical representations, obtained by using the proper software, increases the student imagination and problem-solving (PS) skills.

During the 1990′s Ed Dubinsky and his collaborators developed in the USA with the help of computers the *APOS-ACE instructional treatment of mathematics* (Arnon *et al.*, 2014), which highly reflects the ideas of social constructivism and of the Piaget's theory for learning. The APOS theory argues that the teaching of mathematics should be based on orienting students to use their already existing mental structures and further to build new stronger ones for handling more and more advanced mathematics. The acronym APOS was formed by the initial letters of the words action, process, object and schema, which are the mental structures involved in that process. The interiorization of an action to a process and the categorization of a process to an object are the mental mechanisms involved in the APOS framework. The practical part (teaching schedule) of the Dubinsky's model involves three phases, the initial letters of which form the acronym ACE. Those phases involve Activities in the classroom, use of Computers for promoting the understanding and the student skills on the new topic and Exercises given by the instructor to students as homework in order to embed the acquired new knowledge. The philosophy of the ACE teaching style is that students could be helped to be transferred from a mental structure to the next and more advanced one by participating in a suitably designed—by a specialist or by the teacher—computer activity, where they use the proper software or code to promote their learning skills. The same cycle is usually repeated several times until the categorization of the new knowledge is succeeded. More details and examples about the APOS-ACE instruction, which has been used with success - mainly in university classrooms – for teaching a wide range of mathematical topics, can be found in (Borji and Voskoglou, 2016; Voskoglou, 2013) and in many other related research reports. However, the application of this approach in classroom requires from the teacher, apart for being familiar with the corresponding computer software, to study and understand deeply first the APOS theory. This explains why the APOS-ACE method has not been used widely in school education yet.

Another general—not only for mathematics—teaching methodology that has been developed recently with the help of computers is the *flipped or reverse learning (FL),* which is a mixed process involving both online and traditional teaching in classroom. FL requires inverting the didactic process. Namely, the acquisition of the new knowledge is achieved outside the classroom through the use of digital technological tools (video presentations, mathematical software, etc.) that have been properly designed by the specialists. On the contrary, the traditional homework is done in the classroom directed by the teacher. This inversion promotes the effectiveness of learning and increases the time devoted to problem - solving activities (Lee *et al.*, 2017). FL has its roots to the works of Lage *et al.* (2000) and of Bergmann and Sams (2012), developing online teaching material, so that students could study at any place and any time. FL is highly based on the ideas of social constructivism.

The rapid technological development of the last decades created new complex problems, the solution of which requires not only critical thinking, but also another mode of advanced thinking that has been called *Computational Thinking (CT)*. The term CT, first introduced by Papert (1996), it was brought to the forefront of computer society by Wing (2006). Wing describes CT as "involving solving problems, designing systems and understanding human behavior by drawing on principles of computer science". According to Liu and Wang (2010), CT is a hybrid of other modes of reasoning including abstract, logical, algorithmic, constructive and modeling reasoning. Modeling reasoning combines all the other types of reasoning mentioned above for solving the problem at hand. Voskoglou and Buckley (2012), viewed the problem as a challenge needing a solution and they developed a model elucidating the relationship between critical thinking and CT during the solution, where the existing knowledge is the link between them. CT, as a synthesis of ideas from mathematics, technology and science, forms a new reasoning approach with the potential to create beneficial changes to our society. The best way to learn CT explicitly is through computer programming, which provides a framework for all sciences. However, recent studies addressed the necessity to start training in CT as soon as possible and at any case before learning programming (Kazimoglu *et al.*, 2011).

Reports opposing the use of computers in classrooms focus on the fact that even the brightest students appear to be distracted by the presence of digital devices (Payne Carter *et al.*, 2016). Generally, computers should not be viewed as being capable to solve all existing problems, but rather as performing operations in high speed and therefore facilitating users to spend more time for creative reasoning (Einhorn, 2012). The student practice with arithmetic and algebraic calculations and with the rediscovery of proofs must be continued; otherwise humans will eventually loose the ability to deal with numbers and symbols and the sense of space and time, thus becoming unable for further developments in science and technology (Voskoglou and Buckley, 2012).

4. Applications of Artificial Intelligence to Education

AI is the branch of Computer Science focusing on the theory and practice of creating "clever" machines that mimic the human intelligence and behavior**,** i.e., been able to think, hear, talk, walk and even feel (Kastranis, 2019; Mitchell, 2019). In particular, AI aims to make computers capable to learn from data and make autonomous improvements without depending on commands of a program (*computational intelligence*). In this way computers could become able to build smart models and even to better replicate copies of them selves!

The term AI was coined by John McCarthy in 1956, when he held in Dartmouth College, USA the first academic conference on the subject (Moor, 2006). However, the effort to understand if machines can truly think began much earlier, even before the Alan Turing's abstract *"learning machine"* invention in 1936, which has been proven capable of simulating the logic of any computer's algorithm (Hodges, 2012). AI as a synthesis of ideas from mathematics, engineering, technology and science has rapidly developed since then creating a situation that has the potential to generate enormous benefits to the human society. The spectrum of AI covers many research areas and technologies, like knowledge engineering, data mining, reasoning methodologies, cognitive computing and modeling, machine learning, natural language processing and understanding, artificial planning and scheduling, vision and multimedia systems, intelligent tutoring and learning systems, etc. In this section, recent advances of introducing methods and mechanisms of AI in education, will be discussed.

The attempt to "replicate" teachers by using computers started during the 1970s. Between 1982 and 1984, several studies in the US proved that students who received individual tutoring performed much better than those who didn't. Therefore, a new effort started to re-create the individual tutoring in a computer (adaptive learning systems). AI focuses in general on developing personalized curricula based on each student's specific needs. A grand experiment has started recently in China that could change the way that people learn (Yang, 2019). Squirrel is one of the first China's companies to pursue the concept of an AI tutor. Squirrel's innovation is in its granularity and scale. For every course it offers, its engineering team works with a group of master teachers to divide the subject into the smallest possible conceptual pieces (see Figure 1, retrieved from https://www.technologyreview.com/s/614057/china-squirrel-has-started-a-grand-experiment-in-ai-education-it could-reshape-how-the). Middle school mathematics, for example, is divided to pieces like rational and irrational numbers, properties of a triangle, calculation of areas, Pythagorean theorem, etc. The target is to determine and treat a student's difficulties in each topic in the best possible way.

Figure-1. Squirrel's engineering team working in the laboratory

Unlike Squirrel, Alo7, another big company of China, has developed an online learning platform meant to supplement a traditional classroom. AI implementation is at its beginning in elementary education of China, but in a more advanced level in higher education, especially in the field of civic education. Therefore, Chinese students are prepared and work together to create the proper situation for the future education.

The human-to-human contact that was necessary some decades ago for teaching can nowadays, thanks to the technological progress, be replaced in a great part by virtual teaching using computers, videos, etc. Consequently, it is certain that the *distance learning*, which is usually referred as *e-learning*, will become very important for our lives in future. In E-learning the learning materials are sent electronically to remote learners via a computer network (Goyal, 2012). For instance, the *virtual CoPs* through the Web appear as a very promising tool for teaching and learning mathematics, and not only, especially for developing countries, where people, due to budgetary constraints, it is not easy to travel abroad for participating in scientific, vocational and educational activities (Voskoglou, 2019a). E-learning is also a very useful training tool for the modern companies and businesses, which want to be sure that their staff and partners are equipped with the adequate information and skills needed for their jobs.

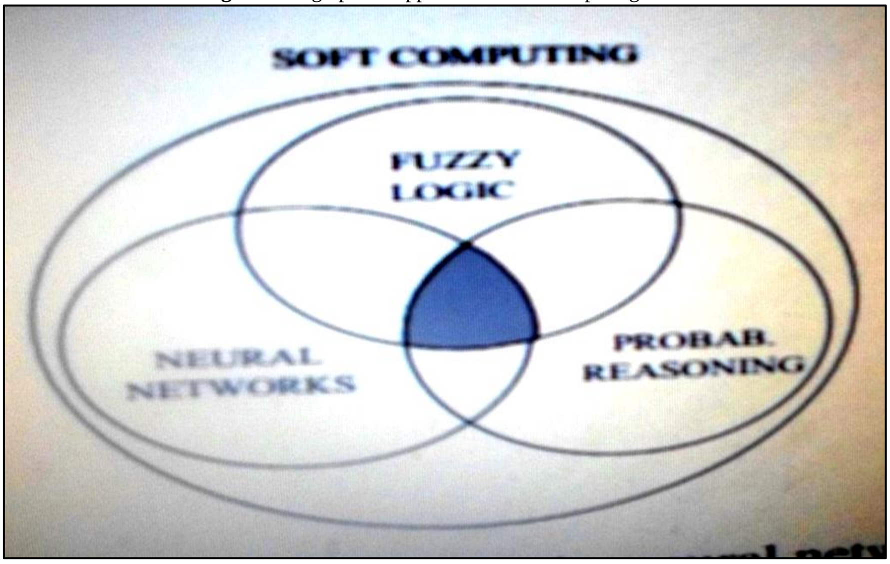
Machine learning (ML) is the branch of AI that refers to any computer program that can "learn" by itself from a training data set. ML includes many types of programs that one can run across in big data analytics and data mining and it is distinguished to *supervised* and *unsupervised* learning (Das *et al.*, 2015). In the former type of learning both input and output data - which play the role of the instructor - are labelled to provide a basis for future data processing. For example, having as input the sequence 1, 2, 3, 4, 5, 6, 7, …, the sequence 1, 4, 8, 16, 25, 35, 49, …. as output corresponds to the raising to the second power. Applications of supervised learning can be distinguished in two categories, *classification* where the output value is a linguistic expression (e.g., true or false), and *regression* where the output is a real value (e.g., price or weight). In the unsupervised learning only the input data provided, and the algorithms are able to function freely in order to learn more about the data. When only some of the input data are labelled with output information, then we speak about *semi-supervised learning*.

Recently researchers have used ML techniques to develop through the Internet a new generation of web-based *smart learning systems (SLS's)* for various educational tasks. A SLS is actually a knowledge - based software used for learning and acting as an intelligent tutor in real teaching and training situations. Such systems have the ability of reasoning and of providing inferences and recommendations by using heuristic, interactive and symbolic processing and by producing results from the big data analytics (Dneprovskaya, 2018; Salem and Parusheva, 2018; Salem, 2019; Salem and Nikitaeva, 2019). The efficiency of a SLS is based on the selection of the appropriate knowledge representation technique and reasoning methodology and the choice of the suitable authoring shell. Therefore, from the technical point of view a SLS is complex to be built and difficult to be maintained. Two are the most popular methodologies used for constructing the knowledge base of a SLS, namely *ontological engineering* and *case-based reasoning (CBR).*

The term "ontology", having its roots to philosophy and metaphysics, refers to the nature of being. The ontologies used in computer science are knowledge-based intelligent systems designed to share knowledge among computers or among computers and people. Those types of ontologies include a relatively small number of concepts, and their main objective is to facilitate reasoning. In intelligent educational systems ontologies are used to help the search of learning materials and pedagogical resources in the internet or as a chain playing the role of a "vocabulary" among heterogeneous educational systems that have been programmed to communicate to each other in the form of multi-agents (Cakula and Salem, 2011).

CBR is the process of solving problems based on the solutions of previously solved analogous problems (past cases). For example, a lawyer who advocates a particular outcome in a trial based on legal precedents is using the CBR methodology. The use of computers enables the CBR systems to preserve a continuously increasing "library" of previously solved problems, referred to as *past cases*, and to retrieve each time the suitable one for solving the corresponding new problem. The CBR approach, apart from commercial and business purposes, has got also a lot of attention over the last decades in education as a new approach to PS and learning (Voskoglou, 2008). In fact, the CBR methodology organizes knowledge in cases of previous problems, each case containing a description of the problem and a solution of it. CBR's coupling to learning occurs as a natural by-product of PS. Effective learning in CBR is referred as *case-based learning*. Also, when an attempt to solve a problem fails, the reason for the failure is remembered in order to avoid the same mistake in future (*failure-driven learning*). More details about the history, development and applications of CBR can be found in (Voskoglou and Salem, 2014) and in the related references contained in it.

Figure-2. A graphical approach of Soft Computing



Fuzzy systems, together with *probabilistic reasoning* and the *artificial neural networks (AANs)* (Voskoglou, 2019c) are the three components of the wider class of *soft computing;* see Figure 2 retrieved from http://users.monash.edu/~app/CSE5301/Lnts/LaD.pdf). AAN's and fuzzy systems try to emulate the operation of the human mind. The AANs, the structure of which is analogous to that of the biological neural networks, concentrate on the "hardware" of the human mind having the ability to learn and to process rabidly the information. On the contrary, fuzzy systems concentrate on the "software" emulating the human reasoning. *A neuro-fuzzy system* is a hybrid system that uses a learning algorithm derived from an AAN to determine its fuzzy parameters (FS and fuzzy rules). Characteristic examples are the *adaptive neuro-fuzzy inference systems (ANFIS)*

The *social robots* could play also an important role in future education. One of the first to develop such kind of robots was Breazeal (2002) in MIT. A social robot is an AI machine that has been designed to interact with humans and other robots. Social robots have been already used for entire job functions at home by understanding speech and facial expressions, in customer service, in education, etc. (Taipale *et al.*, 2015). Two important examples for education are the robot *Tico* that has been designed to improve children's motivation in the classroom and the robot *Bandit* that has been developed to teach social behavior to autistic children. A characteristic sketch about the introduction of smart technologies and robotics in Education, which has been presented by Prof. Abdel-Badeeh Salem in the 23rd International Conference on Information and Software Technologies that took place between 12 and 14 October 2017 at the Kaunas University of Technology, Lithuania, is shown in Figure 3.

Figure-3. Smart Technologies and Robotics in Education

5. Comparing the Artificial and the Traditional Teaching and Learning Methods

The introduction of the techniques of AI has brought significant benefits for Education in general and for the teaching and learning in particular. The most important of those benefits can be summarized as follows:

- Computers provide through the Internet a wealth of information to teachers and learners, while suitably designed by the experts mathematical software packages (SLS's) give to the instructor the opportunity to apply innovative teaching and learning methods in the class, like the ACE instruction, the flipped learning, etc., that increase the student imagination and PS skills..

- E-learning gives to the learner 365 days per year access to the learning subject in contrast to the traditional learning, which is scheduled as a one-time class and requires the learner's physical presence. Another advantage of the e- learning is that it can be used at the same time by a large population spread throughout the world. The e-learning material, once developed as a course, could be easily modified in future for similar uses. Through e-learning students can learn in their own speed what is important for them by skipping unnecessary information. In addition, e-learning is obviously much cheaper than the traditional one, which involves many extra costs (travel, boarding, books, etc.). In concluding, e-learning appears today as a promising alternative to traditional classroom instruction, especially in cases of remote lifelong learning and training, while it can also be used as a complement of the classroom learning .
- When engaged in the CBR approach the students, with many cases available, become able to recognize more alternatives and to benefit from the failures of the others**.** Cases indexed by experts will reveal to students suitable ways of looking at a problem, a thing that they may not have the expertise to do without the help of a CBR system. Research reveals that students learn best when they are presented with examples of PS knowledge and then asked to apply the acquired knowledge to real situations (Voskoglou, 2005). The CBR methodology is useful in particular for cases where there is much to remember, because when reasoning analogically one tends to focus only on the few possible analogous past cases. In general, one could say that a CBR system provides the student with a model of the way that decision making must be done, i.e., what actions ought to be performed for the solution of the problem in hands.
- Apart from helping the instructor in the search of learning materials and pedagogical resources in the internet, ontologies are also useful for the evaluation of the students' learning performance and for recommendations and grouping of them based on their learning behavior and skills. Further, they facilitate the assessment of the learning resources and of the web-based courses (Salem, 2010).

The impressive advances of AI in the field of Education have made these days a number of specialists on the subject to be certain that in future computers and the other "clever" machines of AI will replace teachers in educating students. "When cars invented, horses have stopped to be necessary" they argue parallelizing the two situations. However, although literature experiments have demonstrated that in certain cases artificial learning can be at least as effective as the conventional classroom learning, we are not in a position to claim that it can replace the traditional classroom instruction in general (Goyal, 2012).

In fact, in contrast to the above-mentioned advantages, there are also certain limitations of the artificial with respect to the traditional learning. One of them is that in the distance learning the queries of a student cannot be solved instantly, as the physical presence of the teacher in the classroom guarantees. Also, students in the classroom are pushed through the course to learn, whereas not every student finds e-learning suitable for his or her style. For example, some students feel bored in front of a computer. Apart from the learner's characteristics, there are also many other factors influencing the effectiveness of e-learning, such as media conditions, learning context, technology, etc. that must be taken seriously under consideration. In addition, other important issues like trust, authorization, individual responsibility and security of the Internet must be resolved too. Therefore, although today thousands of online courses are offered by universities all around the world, many of them leading to degree or certificate awards, several uncertain issues and technical problems have to be further investigated concerning the effectiveness and status of artificial learning.

From the philosophical point of view the author of the present article is among those believing that the replacement of the teacher-led instruction by the artificial learning will never actually happen. In fact, learning is mostly a socio-cognitive activity. The acquisition of knowledge is valuable for the students, but the most important thing is to learn how to reason logically and creatively. However, this seems impossible to achieve through the help of the computers and of the other "clever" machines of AI only, because all these devices have been created and programmed by humans. Consequently, although many of them (e.g., computers) impressively exceed humans in speed, it is logical to accept that they will never reach the quality of human reasoning and therefore become able to teach students how to reason logically and creatively (Voskoglou and Buckley, 2012)

6. Discussion and Conclusions

The present work focused on the role that the artificial teaching and learning could play in future education. It was concluded that it is rather difficult that computers and the other "clever" machines of AI will reach the point of replacing teachers for educating students in future. However, it is more than certain that dramatic changes will appear in the future classrooms, since the new technologies appear as having the potential to offer significant benefits for the teaching and learning. Therefore, the investigation of the new teacher's role in the classroom is an interesting subject for future research. This new role requires significant changes or even complete replacement of the traditional teaching methods, proper use of the new technological tools in and out of the classroom, familiarization with the ideas and techniques of distance learning, etc.

Today, the combination of the ML techniques with the latest knowledge acquisition and pedagogical methods has solved many of the technical problems and difficulties appearing in the design of intelligent learning and teaching systems. However, further research is needed on that topic as well for converging knowledge engineering, ML techniques, and educational technology with the forthcoming trends of the advanced *Internet of Things and Energy* (Rifkin, 2014). Such a convergence will create a new generation of intelligent learning and tutoring systems that will enhance further the on-line teaching, learning, and training processes, thus supporting the continuous growth of e-learning in future as an inseparable part of the academic and professional education.

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