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Artificial Intelligence and Digital Technologies in the Future Education

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Abstract

Artificial Intelligence (AI) is the branch of Computer Science that focuses on the theory and practice of creating “smart” devices mimicking human reasoning and behavior. The introduction of the techniques of AI to Education has brought significant benefits to the teaching and learning, to student and teacher assessment and training and to several other educational processes. The present paper focuses on the role that AI and the digital technologies play for Education in the forthcoming era of the Fourth Industrial Revolution, which, under normal conditions, is expected to lead humanity to an era of nearly free energy, goods and services. Thepaper discusses the benefits and limitations of the introduction of techniques of AI in Education. Namely, the role of computers isinvestigated and the expediency of teaching principles of Soft Computingin Education is studied. The advantages and disadvantages of e-learningwith respect to the traditional learning theories and teaching methods are examined, with a special focus on connectivism, a new learning theory in the digital era. The possible role of social robots and the new role of the teacher in future education are also studied and the paper closes with the final conclusions.

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1. Introduction

Artificial Intelligence (AI) is the branch of Computer Science that focuses on the theory and practice of creating “smart”

devices mimicking human reasoning and behavior (Mitchel, 2019, Kastranis, 2019). AI aims at making computers able to perform autonomous improvements with the help of given data without needing the commands of a program created by humans.

The effort to understand if machines can “think” began before the A. Turing’s proposal of an abstract “learning machine” in 1936 (Hodges, 2012), but the term AI is due to J. McCarthy, who organized the first conference on the subject in Dartmouth College, USA in 1956 (Moor, 2006).

As it is illustrated graphically in Figure 1 (Voskoglou & Salem, 2020), AI is an interdisciplinary science synthesizing ideas and methods from a variety of research areas and technologies.

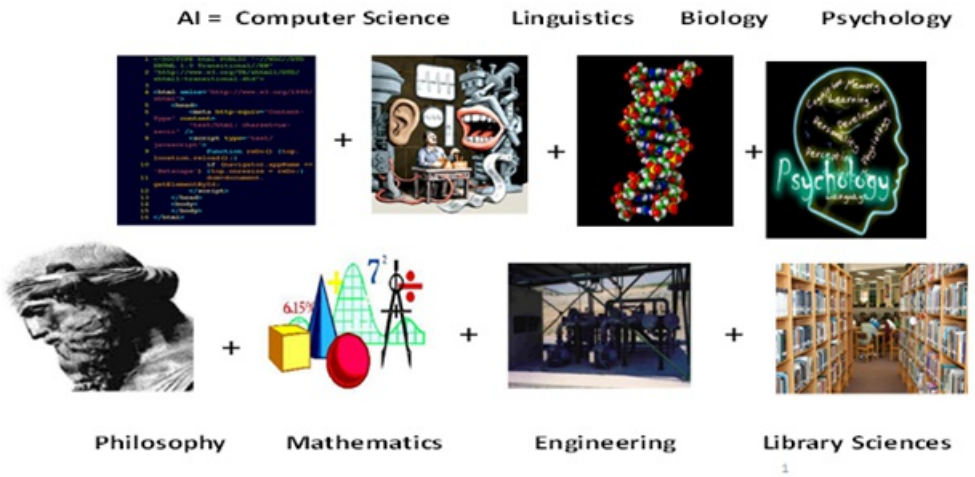

Figure 1. The “spectrum” of AI: A graphical illustration.

The introduction of the techniques of AI to Education has brought significant benefits to the teaching and learning, to student and teacher assessment and training and to several other educational processes. The present paper focuses on the role that AI is going to play for Education in the forthcoming era of the *Fourth Industrial Revolution (4IR)*, which is mainly characterized by the advanced *Internet of Things (IoT)*– providing energy, goods and services at the right time and at any place - and the *Cyber-Physical Systems,* (e.g. robots, autonomous vehicles and control systems, distance medicine, etc.), which will make our lives easier. Under normal conditions, 4IR is expected to lead humanity to an era of nearly free energy, goods and services (Schwab, 2016).

The rest of the paper is organized as follows: Section 2 investigates the role of*computers* and Section 3 studies the expediency of teaching principles of *Soft Computing (SC)* in Education. Section 4 examines the advantages and disadvantages of *e-learning* with respect to the traditional learning theories and teaching methods with a special focus on *connectivism,* a new learning theory in the digital era. The new role of the teacher in future education and other perspectives of further research on the subject are discussed in Section 5 and the paper closes with the final conclusions.

2. Computers in Education

It is widely accepted today that computers are a valuable tool for Education, providing through the web a wealth of information for students and teachers. The animation of figures and representations, achieved by using the proper software, develop the student imagination and enhance their problem-solving skills.

Several didactic methods have been developed in which computers play a dominant role. During the 1990's Ed Dubinsky and his collaborators designed in the USA the *APOS-ACE* approach for teaching and learning mathematics (Arnon et al., 2014). The central idea of the APOS (**A**ction – **P**rocess – **O**bject – **S**chema) theory is that the teaching of Mathematics should focus on helping students to use their already existing mental structures and to build stronger ones for tackling more and more advanced mathematics. This idea is highly influenced by Piaget's learning theory and the principles of social constructivism. 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 theory. The ACE (**A**ctivities in the classroom, **C**omputers – **E**xercises) is the practical part (teaching procedure) of Dubinsky's model. The philosophy of the ACE cycle, which is normally repeated several times, is that students could be oriented to transfer from a mental structure (e.g. action) to the next and more advanced one (e.g. process) by participating to properly designed by experts computer activities (use of a suitable software, of a code, etc.). In the final step, problems and exercises are given by the instructor to students as homework for embedding the new knowledge. The reader can find, among many others, examples of application of the APOS-ACE instructional treatment for teaching the irrational numbers and the polar coordinates in earlier works of the present author (Voskoglou, 2013, Borji & Voskoglou, 2016).

Case-based reasoning (CBR) is the process of solving problems with the help of the solutions of previously solved similar problems (analogical reasoning), referred as *cases.* As a simple example, a physician, based on the treatment of a previous sick patient presenting the same symptoms, gives to the present one the proper treatment. The use of computers enables the creation and maintenance of large "libraries" of past cases and the retrieval from them the most suitable ones for the solution of a given problem. The use of CBR techniques has become very popular today in diagnostic, commercial and industrial applications, but they are also used widely for educational purposes (Voskoglou, 2008).

Flipped learning is another computer-aided didactic approach developed during the last 20 years (Lee et al., 2017, Lage et al., 2000, Bergmann & Sams, 2012). According to it, the new information is acquired outside of the class with the help of proper software, video presentations and other digital means, whereas the traditional homework is realized in the classroom directed by the instructor. In other words, the traditional teaching procedure is inverted through this method, on the purpose of achieving better didactical results.

The rapid development of the new technologies created a series of new complex problems, which cannot be solved with the help of critical thinking alone, but they also need another mode of thinking referred to as *computational thinking (CT).* The term was coined by S. Papert (1996), but it was made widely known to the computer society by J. Wing (2006). CT, which can be roughly defined as an individual's ability to solve problems in the way that computers do, is a synthesis of

other modes of thinking including abstract, logical, constructive, algorithmic and modeling thinking (Liu & Wang, 2010). The model sketched in Figure 2 was introduced by Voskoglou and Buckley (2012) to describe how CT is combined with critical thinking and the existing knowledge for the solution of complex problems. In fact, in this 3D-model the problem is considered as an obstacle and the resultant of the previous three components (knowledge, critical thinking, CT) is applied to pass through the obstacle (problem's solution).

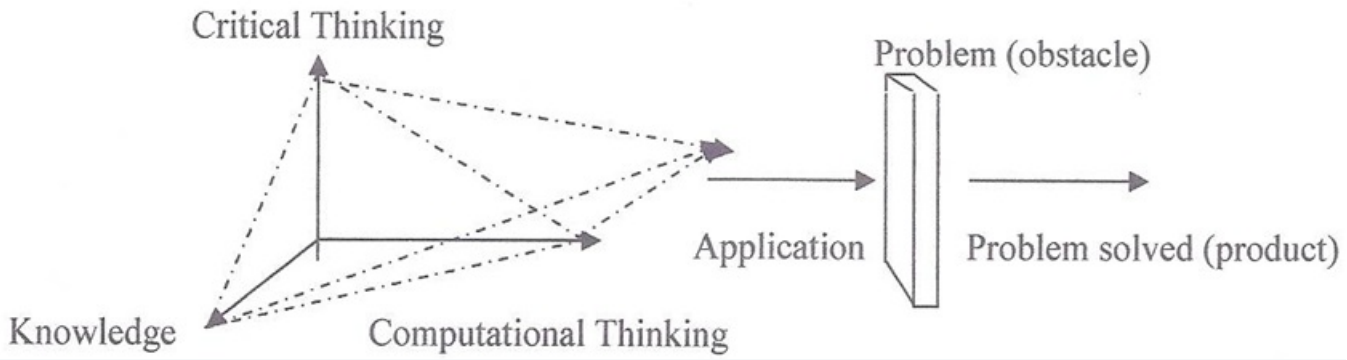

Figure 2. The problem-solving model of Voskoglou and Buckley.

Although the logic of computer programming is useful to almost all sciences, research studies suggest training students in CT as early as possible, before learning programming (Kazimoglu et al., 2011).

Computers, however, should not be considered as being able to do everything, but simply as tools that can significantly help the teaching and learning procedure. This is usually illustrated by the slogan "rubbish in, rubbish out", which characterizes the function of computers. The student practice, therefore, with arithmetic and algebraic calculations and with the rediscovery of proofs must be continued forever. Otherwise, humans will eventually lose the ability of dealing with numbers and symbols and of thinking critically, thus becoming "slaves" of the "smart" machines that have been created by them (Voskoglou & Buckley, 2012)! It is of worth noting that there also exist reports against the use of computers and micro-calculators in classrooms, arguing that even the smartest students are distracted by the presence of digital devices (Payne Carter et al., 2016).

3. Applications of Soft Computing to Education

The term *soft computing (SC),* which is a branch of computer science introduced during the 1980s, is due to Lofti Zadeh (1994). SC simulates the operation of the human mind to reason and learn in an environment of uncertainty and imprecision. It is a synthesis of several topics, mainly including *fuzzy logic (FL)*, *probabilistic reasoning*, *artificial neural networks* (*AANs*) and *genetic algorithms* (*GAs*).

Aristotle's (384-322 BC) *bivalent logic (BL),* based on the "principle of the excluded middle" (everything is either true or false), used to be for more than 23 centuries the basis for the development of science and human civilization. Despite the fact that opposite views about the existence of a third area between true and false appeared early in the human history,

integrated propositions for multi-valued logics introduced only in the early 1900s, mainly by Lukasiewicz (Lejewski, 1967) and Tarski (Encyclopedia Britannica (2018).

Zadeh, based on the concept of *fuzzy set (FS)* (Zadeh, 1965), introduced during the 1970's the infinite-valued FL (Zadeh, 1973), where the truth values are represented by numbers in the unit interval [0, 1]. FL satisfies Lukasiewicz's "principle of valence", according to which propositions can have intermediate truth values (partial truths) between true or false. FL extends and completes the traditional BL by examining what happens in the "area" between true and false. In addition, FL and its generalizations (e.g. see Voskoglou, 2019a) treat effectively all the types of the existing in the real world uncertainty.

A *fuzzy system* is a collection of FSs related and bound together. Fuzzy systems are not only able to use their own knowledge to represent and explain phenomena of the real world, but can also increase it with the help of given data, i.e. they emulate the way in which humans learn, corresponding to the "software" of the human brain.

During the 1990s, E. Jaynes argued that *probability theory* can be viewed as an extension of BL reducing to it when something is absolutely certain or absolutely impossible (Jaynes, 2011). Probability theory, however, the development of which was based on the principles of BL, has been proved suitable for tackling only the cases of uncertainty which are due to randomness {Kosko, 1990), e.g. games of chance. As a result, the Jaynes' probabilistic logic is subordinate to FL.

Bayesian reasoning (BR) appears today as a link between BL and FL (Gentili, 2021, Section 5). It is recalled that the Bayes' rule, which is a straightforward consequence of the well-known formula calculating the traditional probabilities, is expressed in the form

$$P(A/B) = \frac{P(B/A)P(A)}{P(B)}$$

Formula (1) calculates the conditional probability P (A/B) in terms of the *prior probability* P (A) which is fixed before the experiment, the conditional probability P (B/A) of the inverse process, and the *posterior probability* P (B). The last two probabilities are calculated with the help of the experiment's data.

BR has been traced in many everyday life and science situations (Voskoglou & Athanassopoulos, 2020). Recent research has shown that most of the mechanisms of the human brain's function are Bayesian (Bertsch McGrayne, 2012). This makes BR a very powerful tool for AI. Note that fears have been already expressed that the Bayesian machines of AI could become too smart in future leaving humans a second role only (Brockman, 2015)! Sir H. Jeffrey's (1973) characterization, therefore, of the BR as the "Pythagorean theorem of probability theory" is proved to be absolutely justified.

ANNs, which emulate the "hardware" of the human brain, are groups of artificial neurons or nodes connected together in a way analogous to biological networks (Paplinski, 2005, Ibrahim, 2016). The connections of the biological neurons are modeled in ANNs as weights between nodes. Each artificial neuron performs a particular little operation and the overall ANN's operation is the weighted sum of all these operations. AANs are implemented in computer programs for handling

the large number of necessary calculations during the learning process (*neural computing*, Buckley & Hayashi, 1994). A simplified form of the structure of an AAN is illustrated in Figure 3, retrieved from Wikipedia.

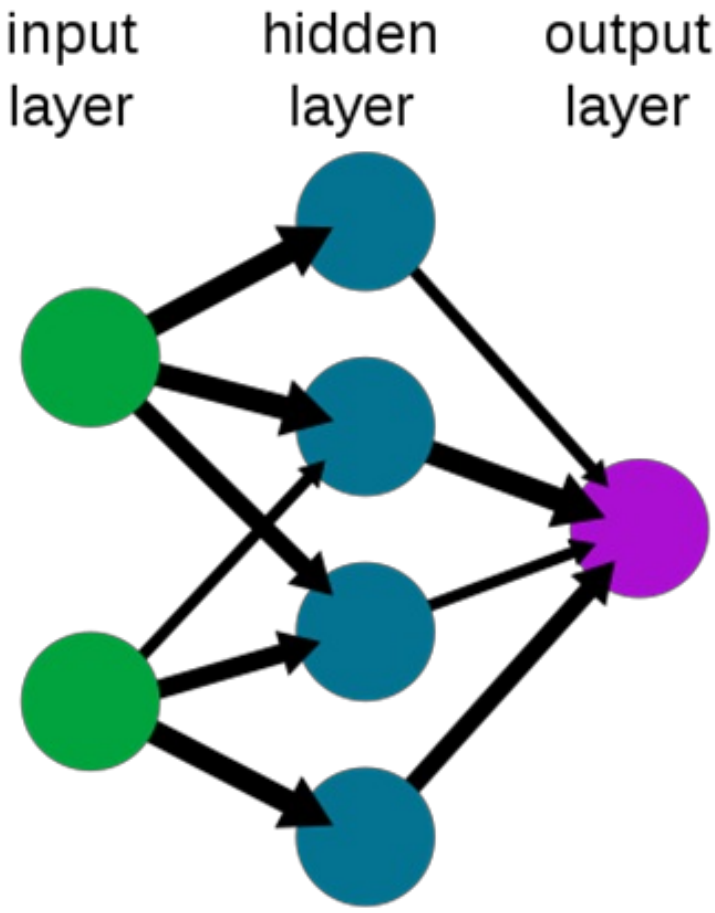

Figure 3. A simplified illustration of the structure of an AAN.

In order to be able to make each set of inputs to produce the desired outputs ANNs must be fed by teaching patterns (training process) for changing their weighting function according to some already imposed to them learning rules. AANs are highly efficient for tackling problems in which there are no algorithms or specific rules to be followed for their solution.

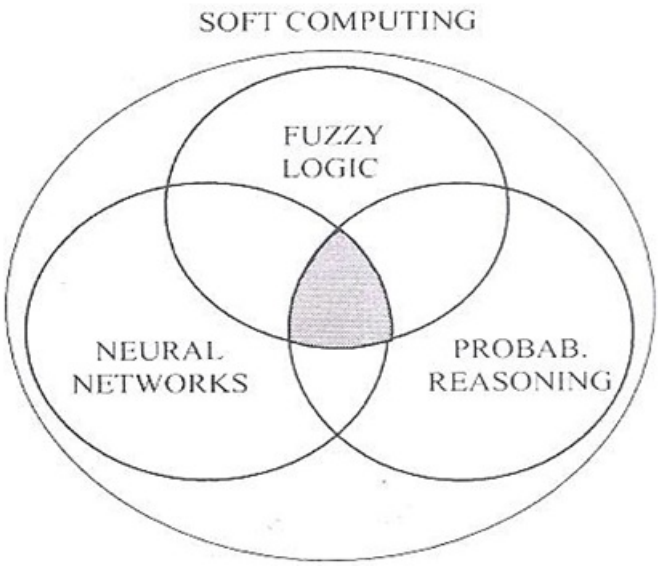

Figure 4. Relationships among FL, ANNs and probabilistic reasoning.

The relationships among ANNs, FL and probabilistic reasoning within the wider class of SC are represented graphically in Figure 4 (Paplinski, 2005). The intersections in Figure 4 represent probabilistic approaches to ANNs and FL systems, Bayesian Reasoning and *neuro-fuzzy systems*, which are hybrid systems using a learning algorithm from an ANN to determine their fuzzy parameters. Characteristic examples are the *adaptive neuro-fuzzy inference systems (ANFIS)* providing accelerated learning capacity and adaptive interpretation possibilities to model complex patterns (Jang, 1997).

The basic idea of GAs is to emulate the natural evolution for finding the best solution to real-life's optimization problems (Ibrahim, 2016, Banzhaf et al., 1998). For example, a GA can search through several designs to find the best combination resulting in the better or cheaper construction of a complex machine. The suitability of a GA depends on the amount of the available information about the corresponding problem; for problems with a great amount of available information more specialized approaches often exist for their solution.

Although SC appeared just during the 1980s, its techniques are nowadays being widely used in many domestic, commercial and industrial applications making it a major research object in automatic control engineering. In the current era of 4IR, as the processing by computer devices is increasing and their cost is reduced, the use of SC methods becomes too important, having the potential to expand further. This underlines the necessity of teaching SC at least to the undergraduate tertiary students.

Probability theory together with *Statistics* have already gained today a dominant position among the subjects taught even to school education. These two, related to each other topics, however, present substantial differences too. In fact, probability studies the evolution of future events, whereas Statistics, starting from the frequencies, obtains conclusions about past events.

FSs and FL have been introduced recently to the syllabuses of several university departments, especially in postgraduate programs. The same, but in a lower degree, also happens with the ANNs and GAs. In an earlier work Voskoglou (2019b)

applied the *5E's instructional treatment* (see Section 4 of the present article) to design a simplified method for teaching the basics of FSs and FL to undergraduate engineering students. He also introduced several methods based on principles of FL for assessing student and teacher performance in educational tasks; e.g. see (Voskoglou, 2019c, 2022) etc.

It is expected that the teaching of the theory and methods of SC will be extended further in the near future, due to its great importance and the variety of its applications to almost all sectors of human activity.

4. Benefits and Limitations of E-Learning with respect to the Traditional Teaching and Learning Methods

Learning, the most important component of human cognition, is connected to the mechanisms of the human brain that enable the acquisition or enhancement of one's knowledge or skills. The ancient Greek philosophers Socrates, Plato and Aristotle explored whether knowledge comes from intellectual reasoning (*rationalism*) or through external observation (*empiricism*) and thousands of years later, during the 17th and 18th centuries AC, the same question was the reason of a historical confrontation in Europe between the rationalist (Descartes, Spinoza, Leibniz, etc.) and empiricist (Hume, Bacon, Locke, etc.) philosophers. By the 19th century the psychologists started to answer this question through systematic studies, the goal being the objective understanding of the mechanisms of learning.

The debate during the 20th century among the learning theorists was centered on whether people learn by changing their behavior due to environmental influences (*behaviorism*, Cherry, 2019)) or by using their brain to construct or expand their knowledge on the basis of new data (*cognitivism,* Wallace, et al., 2007)). During the 1970's, Von Clasersfeld introduced in its typical form a philosophical framework termed as *cognitive constructivism* (Taber, 2011), which is based on Piaget's theory for learning. According to it, knowledge is not passively acquired from the environment, but it is actively constructed by the cognitive mechanisms of the learner.

The combination of the principles of cognitive constructivism with Vygotsky's theory of social development (Crawford, 1996) resulted in the *social constructivism*, which is currently the most popular among the traditional learning theories. According to this theory, learning takes place within a socio-cultural setting, in which shared meanings are formed through negotiation, leading to common knowledge. The *Communities of Practice (CoPs)*, as an example, are groups of experts and/or practitioners in a particular field sharing common interests, who interact regularly (in person or online) to exchange information and experiences on the purpose of developing their personal and/or professional skills with respect their common object (Wenger, 1998, Voskoglou, 2019d).

The role of teaching is to promote learning. A few decades ago the dominant teaching method used to be the*explicit instruction,* which is based on the principles of cognitivism. In this method the teacher tries to transfer in the best possible way the new knowledge to students with clear statements, explanations and supported practice (Doabler & Fien, 2013). Recently, however, a teaching method, termed as the *5 E's instructional treatment* (Hee, et al., 2013), was developed based on the principles of social constructivism, which became very popular, especially in the sector of school education.

The 5 E's method promotes the harmonious interaction among teacher and students, aiming at the acquisition of the new knowledge with the help of the already existing knowledge and the new student experiences. The "5 E's" acronym was created from the initial letters of the five successive phases of the method which are engagement, exploration, explanation, elaboration and evaluation.

A common characteristic of the previous and of all the other (less important) traditional learning theories, which were created before the development of the digital technologies, is the hypothesis that learning is an internal activity of the individual. Nowadays, however, people frequently act by obtaining information stored in a database or an organization, which is termed as *actionable knowledge.* This led to the development of *connectivism,* a new learning theory in the digital era introduced by Siemens (2005) and Dowens (2005). The philosophy of connectivism is that the ability to learn what we need for tomorrow is more important than what we already know. Consequently, when a piece of knowledge is needed but is not known, the ability to plug into sources (connections) that enable us to obtain this knowledge it becomes a necessary skill.

Connectivism, which is a synthesis of principles referred to ANNs, to *self-organization* theory and to the theory of *chaos,* sees knowledge as a network and learning as the process of creating new connections between nodes for expanding the network. Self-organization is understood to be the formation of well-organized structures or behaviors under random conditions (Rocha, 1998). In a self-organizing process the learning system can change its structure in order to classify its interaction with the environment. In contrast to constructivism, which argues that learners attempt to obtain understanding by meaning-making tasks, chaos states that the meaning already exists and the learners' challenge is to recognize its hidden patterns. Chaos recognizes in general the connection of everything to everything (Gleick, 1987).

Studies performed in the USA during 1982-84 proved that students receiving individual tutoring performed better than those who did not (Bloom, 1984). Thus, an effort started to re-create the individual tutoring with the help of computers. China currently leads this effort mainly with two big companies: Squirrel, which pursues the concept of AI tutors for replacing the traditional teachers and Alo7 providing a learning platform supplementary to the traditional classroom (Yang, 2019).

Machine learning (ML) is the branch of AI dealing with computer programs that can learn by themselves from a training data set (Das et al., 2015). It is distinguished to *supervised* and *unsupervised* ML. In the former case both the input and output data are labelled, whereas in the latter case only the input data are provided and the algorithms remain free to learn more about the output data. *Deep learning* (*DL*) (Arnold et al., 2011) is a special form of ML characterized by the many layers that are built in its models (wherefrom it comes the characterization "deep"), which are ANNs. The DL models are suitable for solving difficult computer problems, concerning natural language processing, computer vision, motion of self-driving cars, etc.

Recently ML techniques have been used to design a new generation of web-based *smart learning systems* (*SLSs*). A SLS is a knowledge-based software acting as an intelligent tutor in teaching and training situations (Salem & Parusheva, 2018). The development of a SLS involves the construction of its knowledge base, the selection of the suitable reasoning and inference methodology and the choice of the proper authoring shells, which allow the course instructor to enter the

knowledge base without requiring programming skills and facilitate the entry in it of examples and applications. Two are the most popular methodologies for constructing the knowledge base of a SLS, the use of CBR techniques and ontological engineering. *Ontologies* are used in SLSs to help the search of learning and pedagogical sources in the web and they work also as “vocabularies” in chains of heterogeneous educational systems. In general, the ontologies used in computer science are knowledge-based systems designed to share knowledge among computers, or among computers and people (Tankelevcience & Damasevicius, 2009).

Social robots are devices of AI designed to interact with humans and other robots (Breazeal, 2002, Taipale et al., 2015). They may speak or/and understand speech and facial expressions and currently are used at home, in customer services, in industry, etc. Social robots could also play an important role in future education, current examples being the robot Tico, which has been designed to improve children motivation in the classroom and the robot Bandit developed to teach social behavior in autistic children

From all those discussed in this Section becomes evident that the importance of distance learning, usually referred as *e-learning*, will be increased significantly in future education, since it will be available at any time and place in a much lower cost than the traditional learning including fees, books, accommodation, etc. (Goyal, 2012). Note in addition that one of the consequences of the forthcoming 4IR is expected to be the loss of a number of routine jobs, where computers, robots and other “clever” devices of AI will replace humans. Alternative jobs, however, will also be created concerning the production, maintenance and control of these devices, etc. Consequently, many people will be forced to change their jobs, which underlines the need for extra training and obviously the best way for working people to obtain this training is by using e-learning methods.

There are, however, certain limitations about e-learning too. One of them is that the physical presence in the classroom enables the students to solve instantly, with the help of the teacher, all their possible inquiries about the new subject. Also, relative research has shown that students, and especially the young ones, are distracted by the presence of digital devices (Payne Carter et al., 2016), which are usually necessary for the application of e-learning methods and approaches. Obtaining new information is indeed valuable for students, but more important is to learn how to reason critically and creatively. It is questionable, however, if the latter can be realized only with the help of suitably designed computer programs and the other “clever” devices/methods of AI. All of them are designed and created by humans and, therefore, it is difficult for one to imagine that they could reach or even exceed the quality of human brain and human sense in the near future.

5. Discussion and Conclusions

The combined effects of the three industrial revolutions that took place from the end of the 18th century until recently, replaced the manpower and the power of animals as means of production with machines, facilitated the mass production of goods, improved the social services and led our society to the digital era (Voskoglou, 2020). In the 4IR, which is currently in the beginning of its appearance, the advanced Internet technology, the renewable energy, the 3D-printing and

the development of the cyber-physical systems are merging to lead humanity, provided that no human mistakes and wrong behaviors will interfere, in a new era of progress and well-being. This is expected, however, to change the way of our life, our habits and our behaviors (Schwab, 2016).

In particular, spectacular changes are expected to happen in the area of Education, where the “smart” devices and methods of AI, with the help of computers and the advanced IoT, are going to play a dominant role. The recent advances of AI in Education have already made a number of scientists and informatics professionals believe that the “clever” machines of AI will replace the teachers in the future Education “in the same way as the cars have replaced the horses” some decades ago. Although, according to the opinion of many other specialists, this looks rather difficult to happen in the near future, it is more than certain that dramatic changes are expected to take place with respect to the role of the teacher in the classroom during the next few years. There is an urgent need, therefore, for educators and researchers in the field of education, to suggest suitable ways and practices with the help of which students and teachers will become able to absorb smoothly the forthcoming changes in Education, especially with respect to the teaching and learning processes.

References

- Arnold, L.; Rebecchi, S.; Chevallier, S.; Paugam-Moisy, H. (2011), An introduction to deep learning, in *Proceedings of the European Symposium on Artificial Neural Networks*, Bruges, Belgium, pp. 477–488.
- Arnon, I.; Cottrill, J.; Dubinsky, E.; Oktac, A.; Roa, S.; Trigueros, M.; Weller, K. (2014), *APOS Theory: A Framework for Research and Curriculum Development in Mathematics Education*; Springer: Berlin/Heidelberg, Germany.
- Banzhaf, W., Nordin, P., Keller, R., Francone, F. (1998), *Genetic Programming – An Introduction,* Morgan Kaufmann, San Francisco, USA
- Bergmann, J.; Sams, A. (2012), ***Flip Your Classroom: Reach Every Student in Every Class Every Day***, 1st ed.; ISTE: Washington, DC, USA.
- Bertsch McGrayne, S. (2012), *The Theory that would not die*, Yale University Press, New Haven and London.
- Bloom, B. (1984), The 2 Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring*, Educational Researcher*, 13(6), 4-16.
- Borji, V.; Voskoglou, M.Gr. (2016), Applying the APOS theory to study the student understanding of the polar coordinates. *Am. J. Educ. Res*., 4, 1149–1156.
- Breazeal, C. (2002), *Designing Sociable Robots*, MIT Press: Cambridge, MA, USA.
- Brockman, J. (2015), What do you think about machines that think? Available on http://edge.org/response-detail/26871 (accessed on 12 October 2019).
- Buckley, J.J., Hayashi, Y. (1994), Fuzzy neural networks: A survey, *Fuzzy Sets and Systems*, 66, 1-13.
- Cherry, K. (2019) History and Key Concepts of Behavioral Psychology. Available online: https://www.verywellmind.com/behavioral-psychology-4157183 (accessed on March 18 2020).
- Crawford, K. (1996), Vygotskian approaches in human development in the information era. *Educ. Stud. Math*., *31*, 43–62.

- Das, S.; Day, A.; Pal, A.; Roy, N. (2015), Applications of artificial intelligence in machine learning,*Int. J. Comput. Appl*., 115, 31–41.
- Doabler, T.; Fien, H. (2013), Explicit mathematics instruction: What teachers can do for teaching students with mathematics difficulties, *Interv. Sch. Clin*., 48, 276–285.
- Dowens, S. (2005), An Introduction to Connective Knowledge, available atwww.downes.ca/cgi-bin/page.cgi?post=33034 (retrieved on May, 2, 2020).
- *Encyclopedia Britannica* (2018), Tarski, A.. Available online: www.britannica.com/biography/Alfred-Tarski (accessed on 20 December 2018).
- Gentili. P.L. (2021), Establishing a New Link between Fuzzy Logic, Neuroscience and Quantum Mechanics through Bayesian Probability: Perspectives in Artificial Intelligence and Unconventional Computing, *Molecules,* 26*,* 5987.
- Gleick, J. (1987), *Chaos: The Making of a New Science*. New York, Penguin Books.
- Goyal, S. (**2012)**, E-Learning: Future of education, ***J. Educ. Learn*., 6, 239–242**.
- Hee, J.W., Lee, E.J., Park, H.J., Chang, A.K. & Kim, M.J. (2013), Use of the 5E learning cycle model combined with problem-based learning for fundamentals of a nursing course, *Journal of Nursing Education*, 52 (12), 681-689.
- Hodges, A (2012),. *Alan Turing: The Enigma (The Centenary Edition)*; Princeton University Press: Princeton, NJ, USA.
- Ibrahim, D. (2016), An overview of soft computing, *Procedia Computer Science*, 102, 34-38.
- Jang, J.-S.R (1997)., ANFIS: Adaptive, network-based fuzzy inference system, *IEEE Transactions on Systems, Man and Cybernetics*, *2*3 (3), 665–685.
- Jaynes, E.T. (2011), *Probability Theory: The Logic of Science*, Cambridge University Press, UK, 8th Printing (first published, 2003).
- Jeffreys, H. (1973), *Scientific Inference,* 3d Edition, Cambridge University Press, UK.
- Kastranis, A. (2019), *Artificial Intelligence for People and Business*; O' Reily Media Inc.: Sebastopol, CA, USA.
- Kazimoglu, C.; Kiernan, M.; Bacon, L.; MacKinnon, L. (2011), Understanding computational thinking before programming: Developing guidelines for the design of games to learn introductory programming through game-play. *Int. J. Game-Based Learning*, 1, 30–52.
- Kosko, B (1990), Fuzziness Vs Probability, *Int. J. of General Systems*, 17(2-3), 211-240.
- Lage, M.G.; Platt, G.J.; Tregla, M. (2000), Inverting the classroom: A gateway to create an inclusive learning environment. *J. Econ. Educ*., 31, 30–43.
- Lee, J.; Lim, C.; Kim (2017), H., Development of an instructional design model for flipped learning in higher education. *Educ. Technol. Res. Dev*., *65*, 427–453.
- Liu, J.; Wang, L. (2010), Computational thinking in discrete mathematics. In Proceedings of the IEEE 2nd International Workshop on Education Technology and Computer Science, Wuhan, China, pp. 413–416.
- Lejewski, C. (1967), Jan Lukasiewicz, *Encycl. Philos*., 5, 104–107.
- Mitchell, M. (2019), *Artificial Intelligence: A Guide for Thinking Humans*; Parrar, Straus and Gtraux: New York, NY, USA.
- Moor, J. (2006), The Dartmouth college artificial intelligence conference: The next fifty years. *AI Mag*., 27, 87–91.
- Papert, S. (1996), An exploration in the space of Mathematics Education. *Int. J. Comput. Math*., 1, 95–123.
- Paplinski, A.P. (2005), Basic concepts of Neural Networks and Fuzzy Logic Systems, Available on line

https://www.cic.ipn.mx/~pescamilla/ContInt/Paplinski2005.pdf (accessed on Sept. 12, 2019).

- Payne Carter, S.; Greenberg, K.; Walter, M. (2016), The Impact of Academic Usage in Academic Performance: Evidence from a Randomized Trial on the US Military Academy, *Working Paper #2016.02*, US Military Academy, 2016. Available online: https://seii.mit.edu/research/study/the-impact-of-computer-usage-on-academic-performance-evidence-from-a-randomized-trial-at-the-united-states-military-academy (accessed on March 19, 2020).
- Rocha, L. M. (2020), Selected Self-Organization and the Semiotics of Evolutionary Systems, 1998, available at http://informatics.indiana.edu/rocha/ises.html (retrieved on May, 2, 2020).
- Salem, A.B.M.; Parusheva, S. (2018), Exploiting the knowledge engineering paradigms for designing smart learning systems. *East. -Eur. J. Enterp. Technol*, 2, 38–44.
- Schwab, K. (2016), *The Fourth Industrial Revolution*, Crown Publishing Group: New York, USA.
- Siemens, G. (2005), Connectivism: A learning theory for a digital age, *International Journal of Instructional Technology and Distance Learning*, 2(1), 1-9.
- Taber, K.S. (2011), Constructivism as educational theory: Contingency in learning, and optimally guided instruction.In *Educational Theory*; Hassaskhah, J., Ed.; Nova Science Publishers: Hauppauge, NY, USA,; Chapter 2, pp. 39–61.
- Taipale, S., Vincent, J., Sapio, B., Lugano, G., Fortunati, L. (2015), Introduction: Situating the human in social robots, in *Social Robots from a Human Perspective*; Vincent, J., Taipale, S., Sapio, B., Lugano, G., Fortunati, L. (Eds.), Springer: Dordrecht, Netherlands, pp. 1–17.
- Tankelevcience, L.; Damasevicius, F. (2009), Characteristics for domain ontologies for web based learning and their applications for quality evaluation, *Inform. Educ.*, 8, 131–152.
- Voskoglou, M.Gr. (2008), Case-based reasoning: A recent theory for problem-solving and learning in computers and people. *Commun. Comput. Inf. Sci*., 19, 314–319, Springer, Berlin/Heidelberg, Germany.
- Voskoglou, M. Gr., Buckley, S. (2012), Problem solving and computers in a learning environment. *Egypt. Comput. Sci. J.*, 36, 28–46.
- Voskoglou, M.Gr. (2013), An application of the APOS/ACE approach in teaching the irrational numbers. *J. Math. Sci. Math. Educ.*, 8, 30–47.
- Voskoglou, M.G.; Salem, A.B.M. (2014), Analogy based and case based reasoning: Two sides of the same coin. *arXiv 1405.7567*.
- Voskoglou, M.Gr. (2019a), Generalizations of Fuzzy Sets and Related Theories, in M. Voskoglou (Ed.),*An Essential Guide to Fuzzy Systems,* Nova Science Publishers, NY, pp. 345-352.
- Voskoglou, M.Gr. (2019b), An application of the “5 E’s” Instructional treatment for teaching the concept of the fuzzy set. *Sumer. J. Educ. Linguist. Lit., 2*, 73–76.
- Voskoglou, M.Gr. (2019c), Methods for Assessing Human-Machine Performance under Fuzzy Conditions. *Mathematics*, 7, 230.
- Voskoglou, M.Gr. (2019d), Communities of Practice for Teaching and Learning Mathematics,*American Journal of Educational Research,* 7(6), 186-191.
- Voskoglou, M.Gr., Salem, A.-B.M (2020)., Benefits and Limitations of the Artificial with Respect to the Traditional Learning of Mathematics, *Mathematics*, 8*,* 611.

- Voskoglou, M.Gr., Athanassopoulos E. (2020), The Importance of Bayesian Reasoning in Every Day Life and Science, *International Journal of Education, Development, Society and Technology*, 8(2), 24–33
- Voskoglou, M.Gr. (2020), New Challenges for Education in the Forthcoming Era of the Fourth Industrial Revolution, in S. Buckley (Ed.), *Promoting Inclusive Growth in the Fourth Industrial Revolution*, Chapter 4, 98-117, IGI Global, Hersey, PA., USA.
- Voskoglou, M.Gr. (2022), Application of Soft Sets to Assessment Processes,*American Journal of Applied Mathematics and Statistics*, 10, 1-3.
- Wallace, B.; Ross, A.; Davies, J.B.; Anderson, T. (2007), *The Mind, the Body and the World: Psychology after Cognitivism*; Imprint Academic: Upton Pyne, UK.
- Wenger, E. (1998), *Communities of Practice: Learning, Meaning, and Identity*, Cambridge, Cambridge University Press, UK.
- Wing, J.M. (2006) Computational thinking. *Commun. ACM (Assoc. Comput. Mach.)*, 49, 33–35.
- Yang, X. (2019), Accelerated move to AI in China, *ECNU Rev. Educ.*, 2, 347–352.
- Zadeh, L.A. (1994), Fuzzy logic, neural networks and soft computing,*Communications of the ACM*, 37(3), 77-84.
- Zadeh, L.A. (1965), Fuzzy Sets, *Inf. Control*, 8, 338–353.
- Zadeh, L.A. (1973), Outline of a new approach to the analysis of complex systems and decision processes.*IEEE Trans. Syst. Man Cybern.,* 3, 28–44.