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Thoughts for the Future Education in the Era of the Fourth Industrial Revolution

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Abstract Rapid industrial and technological development of the last 100-150 years has caused radical changes to traditional human society, transforming it into a modern society of knowledge and globalisation. As a result, formal education at all levels, from elementary to university/tertiary, faces the great challenge of preparing students for the forthcoming era of a new but not yet well-known industrial revolution. This new era could be characterised as the era of the Internet of Things and Energy and Cyber-Physical Systems. This chapter focuses on the role computers and Artificial Intelligence could play in future education as well as the risks hiding behind it. It concludes that it is highly unlikely for computers and other "clever" Artificial Intelligence machines to replace teachers in the future, because all these devices were created and programmed by humans. It is therefore logical to accept that they will never be able to achieve the quality and independence of human thought. However, it is certain that the role of the teacher will dramatically change in future classrooms.

Keywords: *Industrial Revolution (IR), Internet of Things and Energy (IoT & E), Cyber-Physical System (CPS), Flipped Learning (FL), Computational Thinking (CT), Artificial Intelligence (AI), Smart Learning Systems (SLS), Case-Based Reasoning (CBR)*

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1. Introduction

The rapid industrial and technological development of the last 100-150 years caused radical changes to our lives and behaviors, transforming the traditional and mainly agrarian human society of the last centuries to a modern society of knowledge and globalization. Machines especially designed for massive industrial production, computers, robots and various other "clever" mechanisms and methods of ***Artificial Intelligence (AI)*** have already replaced humans in an increasing number of routine jobs. This continuous development of new technologies could create many new, yet unforeseen jobs in the future. As a result, formal education, from elementary school to university, is faced with the great challenge of preparing students for a new way of life in a rather uncertain future of the forthcoming era of a new, but not yet explicitly known, industrial revolution, as the outcomes have not yet been fully determined.

The objective of the present work is to express some thoughts about this challenge and the difficulties connected to it. In no case, however, can this article be considered as an attempt to fully analyse the topic mentioned above, because such an effort requires hundreds of pages, as most of the subjects related to education need to be integrated. The focus here is turned mainly to the role computers and AI could play in future education and the risks associated with this perspective.

The rest of this article is organized as follows: In Section 2 a connection is made between the past industrial revolutions and the forthcoming new one, which could be characterized as the era of the ***Internet of Things and Energy (IoT & E)*** and the ***Cyber-Physical Systems (CPS)***. The next two Sections examine the role of computers and ***Computational Thinking (CT)*** in modern education. In Section 5 the recent developments and perspectives of introducing methods and mechanisms of AI to education are studied. The article closes with future directions of research and the final conclusions presented in Sections 6 and 7 respectively.

2. The Industrial Revolutions and the Forthcoming Era of the Internet of Things and Energy

A revolution is defined in general as a rapid and massive series of changes that lead to a radical transformation of human society. It could be a social, political, economic, industrial or other kind of revolution, but involves changes into the core of society.

The ***First Industrial Revolution (1IR)***, which began in the UK's textile factories at the end of the 18th Century and spread throughout the world, involved the gradual replacement of manual labor by mechanical production, where machines were used mainly as power sources. The parallel development in the transportation sector led to the establishment of big industries and companies on a national and later on an international level, for which new scientific functional and management methods had to be developed [1].

Various names and definitions have been proposed for the several industrial revolutions that took place since then. According to the World Economic Forum (WEF), the first industrial revolution, characterized by mechanization, on the basis of steam and water power, was followed by a second one, which started in the middle of the 19th Century. The ***Second Industrial Revolution (2IR)*** used the power of electricity for the mass production of large quantities of standardized goods in assembly lines. However, some social thinkers believe that the 2IR, which ended by the middle of the 20th Century, must be regarded as an inseparable part of the 1IR [2].

Regarding the ***Third Industrial Revolution (3IR),*** or according to Rifkin's [2] view the 2IR, is also known as the ***era of automation*****.** This revolution, which began in the 1940's, was mainly characterized by the development of electronics, automated production and the gradual replacement of the human hand by computers as means of control [1].

In conclusion, the combined effects of those three industrial revolutions have replaced manpower and animals with machines, making mass production of goods possible and leading human society to its current digital era. However, there were undesirable effects as well, such as the negative environmental impact, caused mainly by the unlimited use of coal and petrol and nuclear energy accidents. The economies of many countries are in danger to collapse, the people of the poor countries are suffering with no recovery in sight. Facing the prospect of a new collapse of the global economy, we desperately need a new economic plan that could lead us into a better future.

The idea of a forthcoming new industrial revolution has surfaced at the beginning of the 21st Century [3]. New York Times bestselling author Jeremy Rifkin, a famous social thinker of our time, introduced the term 3IR for this new revolution. In two books published in 2011 and 2014 [2,4] he describes how Internet technology, renewable energy and 3D-printing are merging to form this powerful revolution. The new technology will, for instance, facilitate the distribution of electrical energy or allow smart home and household devices to communicate via the Internet. Consequently, a new advanced IoT & E will be created, providing energy at the right time and place, and goods and services anytime at any place.

The term ***Fourth Industrial Revolution (4IR)*** has an almost identical meaning as Rifkin's 3IR. It was first introduced by Professor Klaus Schwab, Founder and Executive Chairman of the WEF, in an article published in "Foreign Affairs" [5]. In a recent book [6] Prof. Schwab argues that we are already at the beginning of the 4IR. The 4IR is about the emergence of CPS which will be controlled through the Internet by computer programs. Examples of CPS are autonomous automobiles and control systems, distance medicine, robots, etc. The world now has the potential to improve the efficiency of services and organizations greatly and even find ways to regenerate the natural environment from some of the damages caused by previous IR's.

However, Schwab [6] also expresses serious concerns about the great potential risks associated with 4IR in his book. He stresses that our current political, business, educational and social structures need to be fundamentally changed in order to smoothly absorb the resulting 4IR shifts and maximize profits in order to create a better future for our society. This was the theme of the 2016 WEF annual meeting in Davos, titled "Mastering the 4IR". It should be noted that Germany's industrial plan promoted the term ***Industry 4.0*** only for the subset of the 4IR in industry. Furthermore, at the 2019 WEF annual meeting, Japan promoted another round of developments called ***Society 5.0.***

3. Computers in Modern Education

It is hard to deny that in our modern society of knowledge and information computers are a valuable tool for teaching and learning. The wealth of information in the hands of students, animation of figures and representations provided by educational software can serve to increase the students' imagination and problem solving skills. The rich variety of data and resources will help teachers keep their students engaged in the classroom. These are just some of the benefits obtained by using computers in education.

In recent years, an innovative teaching method known as ***Flipped*** or ***Reverse Learning (FL)*** has been promoted using computers. FL, which has its roots in the work of Lage, Piatt and Tegla [7], is a mixed process involving both online and face-to-face teaching. It requires turning around the daily didactic processes which we are accustomed to. In fact, the student's acquisition of new knowledge happens outside the classroom by using digital platforms and technological tools that specialists or teachers have developed. Jonathan Bergmann and Aaron Sams [8] were able to develop online audiovisual teaching materials, thereby enabling students to study regardless of factors such as place and time. On the other hand, what was traditionally undertaken as homework is done in class with the supervision of the teacher in order to favor the productivity of learning and the autonomy of the students and allow more time for practicing, problem solving and deepening of content [9].

The ideas of ***social constructivism*** for learning are used in the development of the FL teaching model. The theory of ***constructivism*** for learning, proposed by Piaget and formally introduced by von Clasersfeld during the 1970's, involves two principles: Firstly, that knowledge is actively built up by the learner, and not passively received from the environment, and secondly the importance of the ***"coming to know"***, which is understood to be a process of adaptation and is constantly changed by the learner's experience of the world [10]. On the other hand, according to Vygotsky's theory of ***social development***, 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. Social constructivism is a synthesis of the ideas of the two learning approaches above [12].

Some years ago, it was believed that teaching required human-to-human contact, but today's technology allows us to do much of this virtually, using computers, videos, etc. Consequently, ***distance learning***, alternatively termed as ***e-learning***, will become an inseparable part of our lives in future. The ***Communities of Practice (CoP's)*** are groups of people, experts or practitioners, sharing a craft or profession. They interact regularly, which allows them the opportunity to develop themselves personally and professionally [13]. By using the Web, ***virtual CoP's*** appear to be a very promising tool for Education, especially for developing countries, where people, due to budgetary constraints, do not have many opportunities to travel abroad to participate in conferences, seminars, educational exchanges, etc. Students and teachers from different countries can form such CoP's for learning particular subjects, while education teachers and researchers can promote teaching and research on teaching [14].

However, there are also reports in literature that speak against the use of computers in classrooms. For example, a study published by the Massachusetts Institute of Technology found that students who were prohibited from using laptops or digital devices in lectures and seminars did better in their exams than those who were allowed to use computers and access the Internet (see 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/). Tom Bennet, who led a UK government-commissioned review on smartphone used in classrooms, noted that even the brightest students appeared to be distracted by the presence of digital devices (see http://www.theguardian.com/education/2015/sep/13/mobile-phone-impact-school-lessons-scrunity). In contrast, a study published by the London School of Economics found that banning mobile phones in classrooms improves the outcomes of low-achieving students, but has no significant impact on high-achievers (see http://www.theguardian.com/education/2015/may/15/mobile-phone-bans-improve-school-exam-results-research-shows).

In general, computers should not be viewed as tools that can perform miracles by solving any kind of problems, but rather as machines performing operations in high speed, therefore enabling users to dedicate their time to quality reasoning and ideas [15]. Since a computer is created and programmed by humans, the old credo "garbage in, garbage out" is still valid. Nevertheless, through programming it is possible to enter information and get output results almost at the speed of light. On the other hand, the practice of students having to do all kinds of calculations is likely to continue, or else people will gradually loose the sense of numbers and symbols, the sense of space and time, and they will become unable to create new knowledge and technology [16].

4. Computational Thinking in Problem Solving

Problem-Solving (PS) is a very important component of the human cognition and has been affecting our lives for ages [1,17]. The ability to solve composite non-routine problems requires ***Critical Thinking (CrT)***, which is a higher mindset that combines analysis, synthesis and evaluation. It also leads to other skills such as inferring, estimating, predicting, generalizing and creative thinking [18]

However, the rapid development of technology in recent decades has led to new complex technological problems the solution of which requires the combination of CrT with a different way of thinking called ***Computational Thinking (CT)***. The term CT was first introduced by S. Papert, who is widely known as the "father' of the Logo software. However, it was brought to the forefront of the computer society by Jeannette Wing [19], who describes it as "involving solving problems, designing systems and understanding human behavior based on principles of computer science". CT includes the analysis and organization of data, the automation of problem-solving and applications involving abstract, logical, algorithmic, constructive and modelling thinking [20]. Modelling thinking synthesizes all previous mindsets in order to find solutions for problems.

CT does however suggest that problems do not necessarily have to be solved exactly the same way as a computer solves them. Voskoglou and Buckley [16] viewed the problem as an obstacle/challenge needing a solution. They presented two alternative approaches to clarify the relationship between CrT and CT during the PS process [21]. The first approach is a 3-D model that could be used to conceptualize the PS process of complex technological problems. In this model, the three components of CrT, CT and existing knowledge act simultaneously on the problem at hand. The model is based on the hypothesis that, if there is sufficient background knowledge, the new (necessary) knowledge is triggered with the help of CrT; then CT is applied and the problem is solved. This model is graphically illustrated in Figure 1.

In the case of simpler problems, the 3-D model could be transformed to the linear form of Figure 2. In this case, the existing knowledge is extracted and critically analyzed, as soon as awareness of the problem is reached. The problem solver then delves into his/her knowledge base and applies the knowledge to solve the problem by thinking in a computer-like manner.

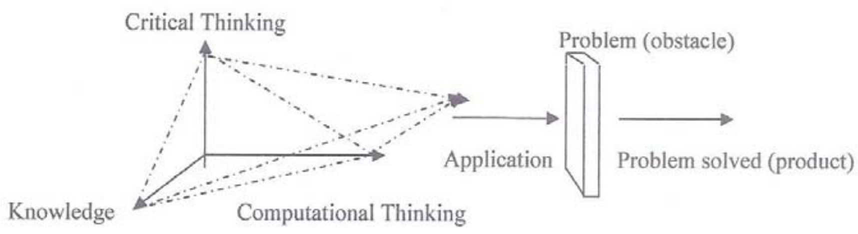

Figure 1. The 3-D problem solving model

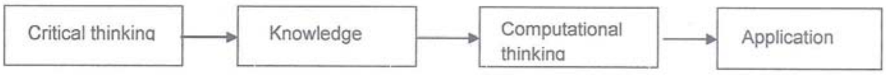

Figure 2. The linear PS model

Recent studies address the necessity of becoming trained in CT before learning ***computer programming*** [22]. However, the best way to learn CT explicitly/thoroughly is through programming. In fact, programming employs all the components of CT and provides a framework not only for computer science, but for all sciences. In thinking like a computer scientist, students become aware of processes that need to be analysed within an algorithmic framework. Thus, CT forms a new way of thinking that has the potential to bring about positive changes in society.

5. Applications of Artificial Intelligence to Education

AI is a branch of Computer Science focusing on the creation of intelligent machines which mimic human reasoning and behavior. The term AI was first coined by John McCarthy (1927-2011) in 1956, when he held the first academic conference in Dartmouth College, USA, on the subject [23]. The commemorative plaque of the 50th anniversary of the conference placed in Dartmouth Hall in 2006 is shown in Figure 3. However, the effort to understand whether machines can truly think began much earlier, even before Alan Turing's abstract "learning machine" invention in 1936, which proved the capability to simulate the logic of any computer's algorithm [24].

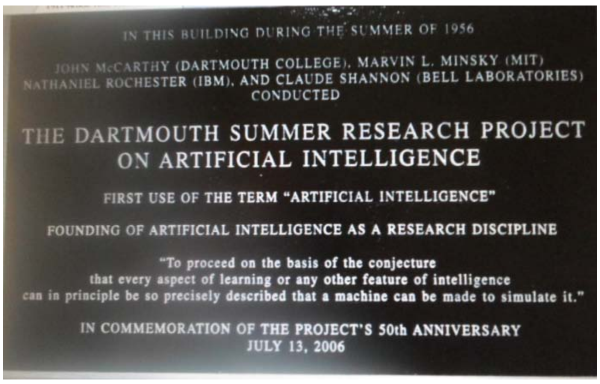

Figure 3. The Dartmouth Hall Commemorative Plaque

AI has its roots in mathematics, engineering, technology and science. Synthesizing ideas from all of these areas has created a new situation, which is just beginning to bring enormous changes and benefits for human society. This section discusses recent advances and perspectives in the introduction of AI methods and mechanisms in education [25]. Among them, ***Machine Learning (ML), Smart Learning Systems (SLS), Case-Based Reasoning (CBR) Systems*** in computers, ***Social Robots*** and ***Fuzzy Systems*** serve as examples.

The term "ML" comes from the idea that an algorithm learns from a training dataset. ML encompasses ***supervised learning,*** in which both input and desired output data can be considered teachers and are classified to provide a learning basis for future data processing, In ***unsupervised learning***, only the input data is given and the algorithms can work freely to learn more about the data. As a simple example of the former case, we consider the sequences of positive integers 1, 2, 3, 4, 5, 6, 7, … as input and 1, 4, 8, 16, 25, 35, 49, …. as output, which indicates the raising to the second power. Applications of supervised learning are typically broken down into 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). If some of the input data is labelled with output information, we speak about ***semi-supervised learning*** [26].

Using the Internet, researchers have recently utilized ML techniques to develop a new generation of web-based SLS for various educational tasks. A SLS is a knowledge-based software used for learning, which acts as an intelligent tutor in real teaching and training situations. Such systems have the ability of reasoning and of providing inferences, interactions, interfaces and recommendations by using heuristic, interactive and symbolic processing and by producing results from the big data analytics [27,28].

The successive phases for developing a SLS are:

• ***Construction of the knowledge base***, involving collection, acquisition and representation of the required knowledge.

The success of the task presupposes the choice appropriate in each case, amongst the many existing, technique (e.g. lists, trees, also semantic networks, frames, production rules, cases, ontologies, etc.) that fit better to the knowledge domain for a solution to the problem.

- ***Selection of suitable reasoning and inference methodology***, e.g. commonsense, model-based, qualitative, causal, geometric, probabilistic or fuzzy reasoning, etc.
- ***Selection of intelligent authoring shells***, which allow the course instructor to easily enter the knowledge domain without requiring computer programming skills.

Those shells facilitate the entry of examples/exercises including problem statements, solution steps and explanations and the integration of suitably developed multimedia course wear by the specialists. The examples may be in the form of scenarios or simulations. In addition to the course knowledge, the instructor has the possibility to specify the pedagogical instruction, i.e. the best way to teach a particular student, and to choose how to assess actions and determine student mastery. The most common authoring shells are DIAG, RIDES-VIVIDS, XAIDA, REDEEM, EON, INTELLIGENT TUTOR, D3 TRAINER, CALAT, INTERBOOK, and PERSUADE [29].

In conclusion, the efficiency of a SLS is based on the selection of the appropriate knowledge representation technique and reasoning methodology and the choice of suitable authoring shells. Therefore, from a technical point of view, a SLS is complex to build and difficult to maintain.

Two of the most popular methodologies used for constructing the knowledge-base of a SLS are ***Ontological Engineering*** and CBR.

The term “ontology” has its roots to philosophy and metaphysics, and 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 in the search for learning materials and pedagogical resources on the internet or as a chain, playing the role of a “vocabulary” among heterogeneous educational systems (*multi-agent systems*) that have been programmed to communicate with each other [30,31].

CBR is the process of solving problems based on the solutions of similar, previously solved problems. For example, a physician who heals a patient based on therapy previously used on patients with similar symptoms, or a lawyer who predicts a particular outcome in a trial based on legal precedents, are using the CBR methodology.

The use of computers enables the CBR systems to preserve a continuously growing ***“library”*** of previously solved problems, referred to as *past cases.* Each time, the suitable previously solved problem can be retrieved for the corresponding new problem. CBR is often used where experts find it difficult to articulate their thinking processes when solving problems. This is because acquiring knowledge in a classical knowledge-based system would be extremely difficult in such cases, and would likely produce incomplete or inaccurate results. When using CBR, the need for knowledge acquisition can be reduced to characterizing cases as an information source.

CBR, as an intelligent-systems’ method, enables information managers to increase efficiency and reduce costs by substantially automating processes. However, the CBR approach, apart from commercial and business purposes, has got a lot of attention over the last decades in education as a new approach to PS and learning [32].

In fact, the CBR methodology organizes knowledge with reference to previous problems. Each case typically contains a description of the problem plus a solution and/or the outcomes. The knowledge and reasoning process used to solve the problem are not recorded, but they are implicit in the solution. This structure/process treats ~~the~~ knowledge in a lesson-oriented manner and facilitates the automatic generation of tests and exercises.

CBR’s coupling to learning occurs as a natural by-product of PS. When a problem is successfully solved, the experience is retained in order to solve similar problems in future. When an attempt to solve a problem fails, the reason for the failure is identified and remembered in order to avoid the same mistake in future. This process is termed as ***failure-driven learning***. Thus CBR is a cyclic and integrated process of solving a problem, learning from the experience, solving a new problem, etc.

Effective learning in CBR, sometimes referred to as ***case-based learning***, requires a well worked out set of methods in order to extract relevant knowledge from the experience, integrate a case into an existing knowledge structure and index the case for later matching with similar cases. In addition, to the knowledge represented by cases, most CBR systems also use general domain knowledge. Representation and use of this domain knowledge includes the integration of the CBR method in other methods, for instance, rule-based systems or in-depth-models such as casual reasoning/commonsense. The overall architecture of the CBR system must determine the interactions and the control relationship between the CBR method and the other components.

The driving force behind the CBR methods comes largely from the ML community and is regarded as a sub-area of ML. In fact, the term CBR not only refers to a particular reasoning method, but also to an ML paradigm, which enables sustainable learning by updating the case base after a problem has been solved. CBR first appeared in commercial systems in the early 1990’s and since then has been used to create numerous applications in a wide range of domains including diagnosis, help-desk applications, assessment, decision support, design, etc. Organizations as diverse as IBM, VISA International, Volkswagen, British Airways, NASA and many others have already made use of CBR.

Despite the fact that the CBR methodology has been proved to be effective in most cases, critics of CBR argue that it is an approach which accepts anecdotal evidence as its main operating principle. But, without statistically relevant data there is no guarantee that the generalization is correct. There is, however, recent work which develops CBR within a statistical framework and formalizes case-based inference as a specific type of probabilistic inference. Thus, it becomes possible to produce case-based predictions equipped with a certain level of confidence.

CBR has been formulated for computers and people as a four step process involving the following actions:

- **R_1: *Retrieve*** from the system’s library a suitable past case.
- **R_2: *Reuse*** this case for the solution of the given problem.
- **R_3: *Revise*** the solution of the retrieved case for solving the new problem.
- **R_4: *Retain*** the revised solution for possible use with similar problems in future.

Through revision, the solution is tested for success. If successful, the revised solution is directly saved in the CBR library, otherwise it is revised and evaluated again. If the final result is a failure, the system tries to compare it to previous similar failures (transfer from R_3 back to R_1) and uses the information in order to understand the present failure, which is finally saved in the library. A graphical representation of the above process is shown in Figure 4 [33].

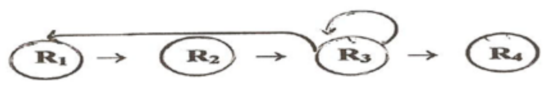

Figure 4. Graphical representation of the CBR process

More details about the history, development and applications of CBR can be found in [34] and in the references provided in this paper corresponding to earlier studies on CBR, in [35], etc.

A social robot is an AI machine that has been designed to interact with humans or other robots. Social robots may understand speech and facial expressions, and are used at home, in customer service, in education, etc. [36]. Cynthia Breazel was one of the first to develop such robots in MIT [37]. Examples of applications in education are the robot ***Tico*** that has been designed to improve children's motivation in the classroom. The robot ***Bandit,*** has been developed to teach social behaviour to autistic children, etc.

The theory of ***Fuzzy Sets (FS),*** introduced by Zadeh in 1965 [38] and its further stage, ***Fuzzy Logic***, which is an infinite-valued logic that generalizes the traditional bi-valued logic constitute to further developments of AI. Fuzzy mathematics today has found many important applications for almost all sectors of human activity; e.g. see [39]: Chapter 6, [40]: Chapters 4-8, etc. Courses on fuzzy mathematics and fuzzy logic have already appeared in the curricula of several university departments [41] and it is expected to expand rapidly in the near future. Since Zadeh introduced the concept of FS and in order to more effectively combat the uncertainty caused by the inaccuracy that characterises many situations in science, technology and our daily life, various generalisations of FS have been proposed (type-2 FS, interval-valued FS, intuitionistic FS, hesitant FS, Pythagorean FS, complex FS, neutrosophic sets, etc.), as well as several alternative theories (grey systems, rough sets, soft sets, etc.); for more details see [42].

AI's impressive advances in education have led a number of professionals and social thinkers to believe that teachers will be replaced by "clever" teaching education machines in future. They argue "when cars were invented, horses became obsolete", parallelising the two situations. However, many others believe that this will never happen. Learning information is indeed valuable for the students, but the most important thing is to learn how to argue logically and creatively. The latter seems to be impossible with only the help of the computers and other "clever" AI devices, since all those devices have been created and programmed by humans. Consequently, although many of those devices impressively exceed the speed of the human brain, it is logical to accept that they will never be able to achieve the quality of thinking of the human mind and sense of humanity.

6. Future Research Directions

This work focused mainly on the role of computers and AI in future education. Although it has been concluded that it is rather unlikely computers and other "clever" AI devices will replace teachers to educate students in future, it is certain that the role of the teacher will change dramatically in future classrooms. This requires changes or even a complete replacement of traditional teaching methods as well as the proper use of the new technological tools, both in and out of the classroom, as well as familiarization with the ideas and techniques of distance learning, etc. An interesting direction for future research is therefore to examine the role of the new teacher.

Obviously, this direction is closely related to the changes that the upcoming 4IR will bring about in society, and the effects which are not yet known exactly. Consequently, preparing our society at large and our students, in particular, to smoothly accommodate these changes is another important impulse for future research.

7. Conclusions

The discussion in this article leads to the following final conclusions:

- The upcoming, but not yet explicitly defined, new industrial revolution (the fourth according to Schwab, or the third according to other social thinkers) could be characterized as the era of IoT & E and the CPS. It has the potential to change our lives by bringing humanity to a better future, provided our society is ready to accept the dramatic changes that will follow.
- Formal Education today faces the major challenge of preparing students for a new way of life (and thinking) in the upcoming 4IR era, with rather uncertain future prospects.
- In this work, the important role computers and AI could play in future education was discussed. However, it is an illusion to believe computers and other "clever" AI machines will replace the teachers for student education in the future, since all these machines were created and programmed by humans and, although many of them outperform people in speed, it is unlikely that they will ever be able to argue like humans do.
- Examining the changing role of teachers in future classrooms and the ways to prepare society to smoothly accommodate the dramatic changes in our lives the forthcoming 4IR will bring about are two important areas of future research.

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