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Educational Technology in the Age of Natural Interfaces and Deep Learning

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***Abstract*—Tools are an essential support in any human activity. As the technology advances, we are able to design more advanced tools that help us in doing the activities more efficiently. Recently, we have seen breakthroughs in the two main components of tools, namely the interface and the computing engine behind. Natural interfaces allow us to communicate with tools in a way better adapted for humans. In relation to the engine, we are shifting from a computing paradigm to another one based on artificial intelligence, which learns as it is used. In this paper, we examine how these technological advances have an impact on education, leading to smart learning environments.**

***Index Terms*— natural interfaces, artificial intelligence, deep learning, smart learning environments, mixed realities.**

I. INTRODUCTION

HUMAN-MACHINE interfaces have been improving at an exponential rate. From command-line interfaces operated with just a keyboard, to graphical user interfaces operated with the addition of a mouse, to natural user interfaces with multimodal interaction through touch, voice, mixed visualizations, sensors, and more.

While this occurs at the "front office", so to say, there have been also considerable improvements at the "back office". We may summarize the evolution as a shift from the computing paradigm to one based on artificial intelligence (AI). Some people say that this reverses the direction of flow. Whereas in computation with inputs and rules (an algorithm) we get outputs, in AI with outputs, many of them, we get rules. This changes completely what can be achieved.

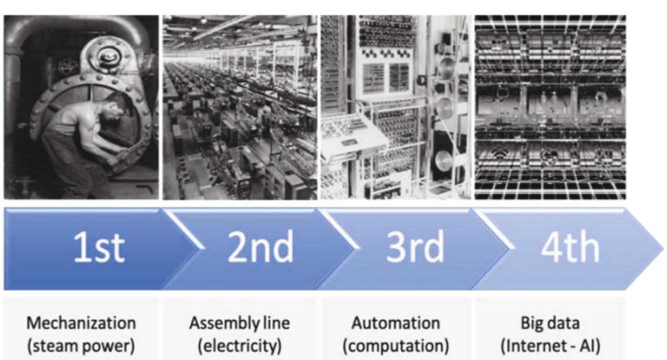

Fig. 1. From Industry 1.0 to Industry 4.0.

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The concept Industry 4.0 [1] (see Figure 1) was coined to reflect the major breakthroughs in industry, from the mechanization thanks to steam power (first revolution) to the assembly line and the availability of electricity (second revolution) to the automation of factories (third revolution), and finally to the availability and processing of big data thanks to Internet services and artificial intelligence [2]. In a similar way, we can identify four major revolutions in education, although they do not correspond exactly to the same time periods and technologies as in the case of industry (see Figure 2).

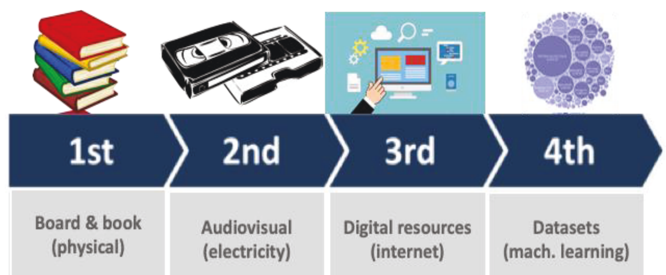

Fig. 2. From Education 1.0 to Education 4.0.

The first one corresponds to the invention of the printing press. This brought a higher efficiency in book production and therefore a faster and wider dissemination of knowledge. Into Education 1.0 we can include also the blackboard, although it is only a bit more than 200 years old. In this way, we cover all physical, mechanical technologies that can be used both for the dissemination of knowledge in books and for the explanation in class. Interaction, so essential for learning, takes place physically, in a controlled physical environment in which students can experiment with real objects they have at hand (e.g., chemical elements to understand reaction processes in Chemistry, corpses to perform a dissection in Medicine, etc.). Collaboration between students takes place at this level in a face-to-face environment, and in a synchronous way.

For Education 2.0, electricity is necessary. Education 1.0 can be carried out without electricity. Education 2.0 cannot. A computer and a projector could be used, but no internet is required. This level corresponds to typically using slides and a slide projector or even a computer with PowerPoint or similar tools and a computer projector in class. This is today a widely used setting [3]. In this case, interaction no longer requires a dedicated physical space. Simulators can be used to carry out experiments where the real elements are unavailable, simulating the behavior of the environment under study (e.g., the result of two molecules when colliding in Chemistry, the behavior of the circulatory system in Medicine, etc.). Collaboration between students still happens in a face-to-face environment, and needs to be synchronous, although it can be mediated by technology, leading to the emergence of the field of research called Computer Supported Collaborative Learning (CSCL).

Education 3.0 is enabled by internet and cloud computing [4]. MOOC (Massive Open Online Course) platforms are a good representative of this revolution [5]. Content is in the cloud and discussion forums as well. Both teacher explanations, typically through videos, and interactions among actors (teachers and students) go through the cloud. LMSs (Learning Management Systems), as earlier, possibly less developed ancestors of MOOC platforms, also fall into this category. They were used basically for out-of-class usage [6]. The use of mobile apps for engagement in class, such as Kahoot! or Socrative, is also a good use case [7]. They promote active pedagogies in class. Note the difference to the use of PowerPoint, where information flow goes one way from the teacher to the student and feedback has to go through the physical channel, which greatly limits the students' interaction. However, with mobile engagement apps interaction goes through the cloud at a much higher bandwidth: all students can give feedback. Therefore, the individual student can (must) interact more with the teacher [8]. In this case, more powerful simulations become available for students, as processing capabilities rely on the cloud. Moreover, students can make use of remote laboratories in which to experiment (remotely) with real elements, but at a much lower cost. Collaboration now can happen virtually, and be synchronous (e.g., through a videoconference tool, or a shared online document) or asynchronous (for example, through the forum in an LMS or MOOC platform). Numerous technologies have been used to support students in their learning processes in Education 3.0, such as internet-based CSCL, augmented reality, adaptive learning, intelligent tutoring systems, gamification, etc.

We arrive now to Education 4.0, which we define as being enabled by machine learning [9]. Some might say that machine learning is still software and therefore does not qualify to be called a new revolution. However, computing takes input data and some rules (the algorithm) to get output data, whereas with machine learning it is the opposite: with (lots of) data we get the rules. We are presently just scratching the surface of what is possible with learning analytics [10]. This opens the way for learning how students learn and how learning can be adapted to each of them. The opportunities are great, although they come with ethical challenges as well [11].

This paper is an extension of a conference paper presented in IEEE 2019 EDUCON [12], and granted with the Best Paper Award on the Area 1: "Infrastructure and Technologies for Engineering Education". As such, this paper delves into the transformation from Education 3.0 to Education 4.0.

II. Education 3.0

The advent of MOOC platforms and variants have shown the world that technology has great potential that has not yet been harnessed. What do platforms like Khan Academy, edX, or Coursera have in common? For us, the essence is the deployment of cloud computing for educational purposes.

On top of it, there are three main components (as represented in Figure 3) related to the educational interface:

- Short videos for explanation of concepts;
- Interactive quizzes for brain training;
- Forums for interaction among students and with faculty.

The relationship between cloud computing and these three components as the core of Education 3.0 was introduced in [12], and later on also mentioned by Anant Agarwal, Founder and CEO of edX, as the four enabling technologies which created the perfect storm for online learning [13]. The only difference is that Anant Agarwal includes gamification instead of interactive quizzes in these four technologies, although he actually highlights the immediate feedback enabled by interactive quizzes as a way of gamification.

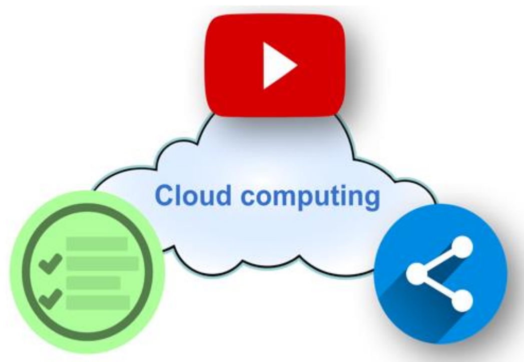

Fig. 3. Cloud computing as the basis for educational technology of the last decade.

III. Machine Learning

Machine learning techniques can be applied in education with different purposes. For example, they can be used to adapt the learning process providing different personalized resources, to create a dialogue with the student providing useful feedback, to form groups of students, to calculate useful higher-level indicators from low-level data, or to predict different future behaviors.

Machine learning techniques can try to imitate some human behaviors as these can be modelled to improve the learning process. In addition, machine learning techniques can go further to achieve aspects that human teachers could not achieve so efficiently, such as to apply complex models for skill modelling [14] or to predict students' performance (grades, drop-outs, etc.) [15].

In distributed Internet of Things (IoT) scenarios, data from different sources can be collected and analyzed in an integrated way. However, different interoperability issues need to be solved: at a format level, learner events should be collected with a common format, and at a semantic level, similar indicators, visualizations, etc. should be defined when combining data from different platforms where their meaning might differ. For example, interactions from a web learning platform, a voice assistant or an external e-learning service could be integrated.

At a *format level*, xAPI [16] is probably the most extended specification at the moment. But there are other possible specifications, such as Contextualized Attention Metadata [17], IMS Calliper [18] or platform-dependent specifications. Most of them enable the representation of different events as "subject-verb-object" and add additional information, such as the timestamp or the context, where the subject is the learner, the verb is the type of action, and the object is the educational resource the learner is interacting with. This type of format allows data from different sources to be combined and analyzed as a whole.

Therefore, one possible solution is the transformation of all events collected from several systems to a common format. However, multiple systems are already running with several formats and it would be time consuming. One proposal is not to transform this data at a low level, but to allow interoperability at a higher level, enabling multiple formats when storing events. This way, each platform, sensor, etc. would use a different low-level format but there would be an interoperability layer at a higher level. For example, there could be high-level indicators such as the students' ability, and all distributed systems would be able to provide an indicator like this, so that this information can be combined at a higher level. Each distributed educational system could have a connector to transform from the specific format to a high-level information format. The high-level layer should be careful designed so that it enables the desired combinations from different resources.

At a *semantic level*, for example, one platform could allow one attempt per exercise, another platform three attempts, another platform an undefined number of attempts up to a correct resolution, or no limit in the maximum number of attempts. This implies that if we calculate the number of attempts in an exercise the interpretation could be different in each platform or that there might be indicators that are present in one platform but not in the others. This issue can be extended for the definition of indicators when we use multiple sources and can also be formulated for visualizations and for interventions. There is a need for some common framework to enable different interoperability at a semantic level when combining different sources.

The semantic layer can be achieved with different technologies, such as ontologies. Ontologies are a natural way to address this issue since they provide a complete modelling, defining the terms and their relationships so that application reasoners can make decisions.

In quite a few occasions, machines cannot make accurate decisions alone about educational processes and interventions from teachers, students or manager are needed. For example, there are contexts in which information from dashboards should be interpreted to make decisions. Therefore, there is a human component that has to be combined with machine learning. It is important to enable capacity building for relevant stakeholders so that they can understand the outputs of machine learning to make together better decisions. In this direction, it is very important the adoption of learning analytics at institutions, with efforts such as the SHEILA project [19].

All in all, three key topics related to machine learning are discussed next as the basis for Education 4.0, and as an evolution of the three main components of the use of cloud computing for educational purposes in Education 3.0 (see Figure 4): (1) *mixed realities*, as an evolution of educational videos; 2) *multimodal interaction* as an evolution of interactive activities; and 3) *mixed social networks* as an evolution of traditional social tools for students and teacher-student communication. Machine learning and these three new components are also mentioned by Anant Agarwal with some minor differences, as Anant focuses on Artificial Intelligence, big data analytics, mixed realities (AR/VR) and robotics as the next four big technological movements which will impact education in the next decade [13].

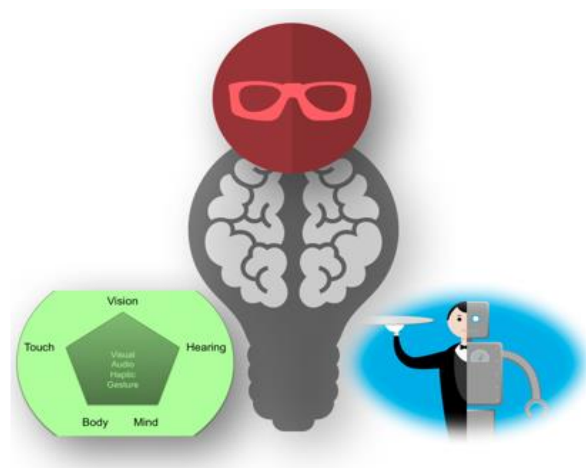

Fig. 4. Machine learning as the basis for educational technology of the next decade.

IV. MIXED REALITIES

Mixed realities refer to technologies in which physical and virtual elements of an ecosystem, such as users, locations and objects, interact. The proportion of physical and digital elements as well as interactions among them in both worlds can be regulated depending on the objective to be achieved. Milgram's continuum [20] offers a form of representation that goes from the purely physical world in one side to the purely digital world (virtual worlds) in the other side. The mixed reality would be located in the central part of this continuum where a significant percentage of physical and virtual elements coexist, and the potential of both worlds can be exploited.

One of the main advantages of the physical world is everything related to the sense of touch and the manipulation of objects since other senses such as sight and hearing are more easily replaced by technology. In addition, one of the advantages of the virtual world is the ability to monitor any interaction that occurs in the environment and recreate non-existent environments, or modify the scale of existing ones (small, large or imperceptible by the human eye) to put them on the scale of the user to be explored by humans. Mixed reality is a very broad technology and offers enormous potential, but its use for educational support implies new challenges that must be considered, many of which are not yet resolved [21].

Some of the advantages of mixed reality applied to education is that it allows students' interaction with digital objects with two main advantages: (1) immersion and contextualization are provided by the real environment; and (2) personalization can be achieved thanks to the virtual or digital environment. For students, learning activities in these mixed environments promote positive psychological emotions that help them in their learning processes. For educators, mixed realities allow better monitoring of the learning processes and open possibilities for guiding students through their whole learning experience.

Beside these affordances, mixed reality research applied to education is still at an early stage. Most of the works in this area are still based on particular case studies that are often difficult to extrapolate to other contexts. In addition, there is still no consensus in the community about the design patterns and usability principles that should be applied to mixed reality environments, or about the conditions that affect the educational effectiveness of a particular design applied to a domain of knowledge. However, the application of mixed reality to different educational methodologies, such as context-based learning, role-based learning, and task-based and problem-based learning, is allowing the re-conceptualization of some educational terms, such as contextualization, engagement and authenticity, taking them to a new dimension [21].

If the focus is placed on locations (*context-based learning*), mixed realities are cheaper to deploy than their counterparts, 3D virtual environments, which require a complete digitalization of learning environments that sometimes do not look as realistic as students demand. The real world can be used as the scenario where pertinent activities can be performed by students. Additionally, the use of a real environment has the advantage of facilitating the immersion in learning activities. This has been widely used for on-site learning in work environments. Health professionals make simulations of clinical cases using simulated patients in real environments, in their own workplace with the same equipment they use in their daily life [22]. The opposite approach is also possible when different complex environments are recreated virtually. This approach is used, for example, by driving simulators that recreate different roads and weather situations without the need to search for specific locations [23]. Virtual environments are also widely used for training first responders (police, firefighters, soldiers or healthcare professionals) in emergencies to recreate the environment of an accident, a natural catastrophe, or a terrorist attack as these environments would be very expensive to replicate in the real world [24]. Other examples of use are sports training or training people with disabilities [25] where it is possible to recreate different urban barriers to face them repeatedly in a safe environment. In some learning scenarios the same location can be replicated physically and virtually to differentiate the tasks that can be done online from those that require face-to-face interaction [26]. Informal learning spaces, such as museums, can also be increased with storytelling and curricular content to provide new scenarios for learning in urban environments [27]. All these approaches offer a new meaning to the context, are supported by ubiquitous learning and make connections between formal and informal learning.

If the focus is put on people (*role-based learning*), technology allows regulating student engagement from a physical, mental or emotional point of view [28]. Mixed realities can be used to deploy learning activities where students can discover by themselves and through interactions new knowledge, new abilities, and new competencies. This active way of learning has been found to be more motivating and attractive for students, encourages concentration, and improves learning outcomes. In this case mixed reality allows observing the world from different points of view through role-playing where the student can address the situation in first or third person and assuming one single role or several roles. This immersion and embodiment can be applied both to young children, for example, to become characters in a book [29], and in adult learning where a doctor can address a problem by assuming the role of different people (doctors, nurses or even the patient himself) [30].

If the focus is placed on tasks (*task-based and problem-based learning*), in order to deploy worthwhile learning activities, it is necessary to design workflows for students to follow. These workflows should be driven both by students' interactions with the digital objects provided and by the personalization that the learning environment can infer from student previously known data. These workflows can be easily integrated into the mixed learning environment. Gamification and storytelling can help to define these flows as shown in the PhyMEL methodology (Physical, Mental and Emotional Learning) [28], and technology can help to simplify tasks and decide what degree of complexity is visible or hidden depending on the phase of learning. This is interesting for learning complex STEM concepts such as electromagnetism [31], or even more complex tasks in professional environments, such as laparoscopic surgery.

All in all, mixed realities constitute a more natural interface that opens up new educational possibilities when used in conjunction with cloud computing and machine learning. The use of cloud computing allows the deployment of collaborative augmented educational environments while machine learning allows intelligent support to educational processes in these intelligent environments.

V. Multimodal Interaction

Voice assistants, or more broadly speaking conversational agents, consolidated in the last few years as an outstanding form of communication between computer systems and humans, thanks to great advances in natural language understanding, machine learning algorithms, and artificial intelligence [32]. The use of voice assistants both in the workplace and at home was promoted by the recent commercialization of smart speakers, such as Amazon Echo, Apple HomePod, and Google Home, among others, at an affordable price. This makes voice assistants the next big technological leap after websites and mobile applications for many people. The use of voice assistants in education has barely been explored so far, despite their great potential to support, for example, students' learning processes when they are alone and need to cope with complex tasks without the presence (and support) of the instructor.

One of the main objectives of the research field which focuses on human-computer interaction is to make the interaction between computer systems and individuals more human. The inclusion of voice assistants allows for a new form of communication between computers and human beings, i.e. through voice (and natural language). Speech is essentially a human activity and the development of devices and applications that can implement voice recognition and respond to the user precisely using also the voice represents a new form of communication with computers, which is not exempt from challenges and ethical dilemmas [33].

In the area of education, and particularly in the field of technology-enhanced learning, the addition of voice as a communication channel between computer systems and the many human stakeholders (students, teachers, managers, etc.) does not necessarily imply new functionalities, but rather a new form of interaction. The same functionality can be provided by a computer system with text, voice or a touch screen, since one can be translated into the others: they are simply different interfaces (different modes) for the interaction between the computer system and the individual. It is then possible to talk of multimodal interaction in education [12].

The use of voice assistants in education has several important advantages that can lead for example to students preferring them to systems based on another type of interaction such as text-based, or touch-based interaction: (1) communication through voice and natural language is more straightforward, intuitive and rewarding; (2) speaking is typically faster than writing or handling a touch screen, which means more efficient communication. This is especially true for people who are not accustomed to new technologies, but who could get used to them through the mediation of voice assistants. There is no need to learn how to use a computer or a smartphone, just to talk to a voice assistant as if it were someone else. In addition, voice assistants are gradually integrated into numerous other devices, such as smart speakers or household appliances, which can be configured more and more and allow the programming of routines through voice commands. Finally, a person, for example, a student, may do multiple tasks at the same time and interact with a voice assistant in a natural way, which is more complicated than with other types of interfaces, such as textual ones, which require more attention.

Nevertheless, there are also important challenges which emerge with the introduction of voice assistants in education, most of which are not specific to this particular context, but more general challenges of voice assistants. The first challenge is the recognition of the student's voice. The voice assistant must be able to recognize multiple students' voices with different tones, speeds, distances, etc. Sometimes the process of voice recognition fails, and the student needs to repeat instructions or commands several times until a correct understanding is achieved. The second challenge is the dialogue interaction. Ideally, the voice assistant should have the proper intelligence to speak in full dialogue with the student. In reality, however, the interaction is usually limited to a few predefined statements. Although there are already dialogue tutors which can adapt and respond automatically to multiple statements and this can be replicated in a voice interface, this artificial intelligence is not yet as powerful as another person speaking. Therefore, the different possible statements must be clear to the students so that they do not feel frustrated or lose interest. The third challenge is that there must be a clear differentiation between possible voice statements for student interactions with the application and voice statements for navigation in the several application menus. Finally, it is important to take into account the ethical challenges which include, among others, the collection and storage of information from voice interactions between the student and the voice assistant, and the fact that the devices which integrate voice assistants are asleep, but listening, while waiting for the next indications from the students [33].

Voice assistants in education may work independently of, or integrated with, other services, both for applications that make use of voice assistants and devices that include voice assistants. For example, if a distributed service-oriented architecture is defined as an educational ecosystem in which students use instances of services and platforms (provided locally by the educational institution or through the cloud), then applications which include voice assistants could be used as one of these services. Nevertheless, devices that include voice assistants could be seen as digital sensors in an Internet of Things (IoT) scenario.

Currently there are few articles in the literature which have presented uses of voice assistants in real educational settings, and that is why there is an important research opportunity in this field. For example, a first related work focused on improving peer learning through a conversational agent which mediated the conversation, resulting in an improvement of both individual and group learning, according to its authors [34]. Another work was Java PAL [35][36], a conversational agent built on Google Assistant which was designed with the aim to help students from a MOOC on programming with Java to review core concepts. This conversational agent included two operation modes: (1) quiz mode, in which the voice assistant challenged the student with questions collected from the MOOC; and (2) review mode, in which the student could ask for definitions of concepts and the conversational agent, besides providing the proper definitions, suggested related concepts to be reviewed.

VI. MIXED SOCIAL NETWORKS

Social interaction is a fundamental element in the learning experience, both in terms of the interaction of the teacher with the students and in terms of the interaction of the students with each other. In face-to-face educational environments, this interaction is facilitated through physical contact among students and between students and the teacher. In virtual educational environments, physical interaction is replaced by other forms of communication supported by technology, such as forums or wikis (for asynchronous communication) or video conferences and chats (for synchronous communication) [37]. In both face-to-face and virtual educational environments teachers can foster social interaction through collaborative activities and the promotion of the use of communication tools [38].

Nevertheless, in virtual educational environments where there is a large number of learners enrolled, such as in MOOCs (Massive Open Online Courses), synchronous communication can be problematic and, in general, asynchronous communication is preferred (mainly among learners with limited teacher intervention). Studies on social interaction in MOOCs stress that learners prefer the forum as the main asynchronous communication tool, over other communication tools, such as Facebook or Twitter [39][40]. It is noteworthy that thousands, and even tens of thousands of messages can be generated by learners in the forum of one single MOOC, hindering the learning experience in multiple ways. First, teachers may find difficulties in detecting the most critical and urgent messages in such a large number of posts in the MOOC forum. Second (and as a consequence of the first problem), learners may not get answers to their questions in a reasonable amount of time, preventing them from moving forward in the course. In order to alleviate these problems, it is possible to find learners in many MOOCs who altruistically devote their time to helping their peers. The identification of these "community teaching assistants" is essential at an early stage in order to provide them with special permissions to better help teachers in managing the MOOC forum [41]. In addition, methodologies and tools, such as 3S and LATƎS [42], have been proposed in the related literature to help teachers and learners digest and understand the large number of messages posted in the forum by detecting the most important topics discussed.

In educational contexts where large amounts of data are collected, such as MOOCs in general, and MOOC forums (when focusing in social interaction) in particular, machine learning algorithms can be helpful. It is possible to collect the messages published by the learners in a MOOC forum and analyze, for example, the quality of the messages (measured for instance as relevance in the scope of the course), the polarity of the messages based on the terms used (positive, negative or neutral), or learners' behavioral patterns (identified for instance through the frequency and quality of the messages published by each learner). There are several research papers related to message processing in MOOC forums which stand out. For example, authors in [43] concluded that it is possible to use unsupervised machine learning models initially developed for synchronous conversations in order to understand asynchronous discussions in MOOC forums. In another relevant work, the authors of [44] developed algorithms for the extraction of key terms and ranked the discussion topics according to their relevance; these algorithms were tested with data collected from several MOOCs offered in Coursera. It is also worth noting the work presented in [45], in which the authors analyzed cognitively relevant students' behaviors with data collected from a MOOC discussion forum, including the relationship between the quantity and quality of published messages and learning gains, proposing a machine learning model to predict these behaviors. Finally, the authors in [46] compared supervised and unsupervised machine learning algorithms to carry out a basic analysis of learners' emotions with the messages published in a MOOC forum, proposing as future lines of work the identification of more complex human emotions, such as boredom, excitement or frustration, from the information available in MOOC forums.

A step forward in the humanization of discussions in forums and social networks in cases where the teacher does not have the capacity or time to solve all questions (as in the case of MOOCs in virtual educational environments), is the use of virtual "non-human" teaching assistants. Virtual teaching assistants can be understood as intelligent systems aimed at improving the learning experience by providing personalized information at the learners' request [47]. Virtual teaching assistants can support synchronous communication in chats (chatbots) or asynchronous communication in forums. For example, the Georgia Institute of Technology (Georgia Tech) has extensive experience in the use of virtual teaching assistants to support course forums [48][49]. The first time Georgia Tech built a virtual teaching assistant was in 2015. Its name was Jill Watson, it used IBM Watson APIs [50], and it was designed to support forum discussion in an online course on Knowledge-Based Artificial Intelligence. Later versions of Jill Watson were built from scratch, using an external open source library, and had different names as teaching assistants in different courses (for greater "humanization"): Ian Braun, Stacy Sisko, Cassidy Kimball, Liz Duncan, etc. [48]. Interestingly, learners' reaction to the use of virtual teaching assistants to support online discussion forums was "uniformly and overwhelmingly positive", as reported by the authors in [48].

All in all, the use of machine learning algorithms and artificial intelligence, along with traditional course forum supervision by teachers (and "community teaching assistants" in the case of MOOCs), is intended to enrich the learning experience in virtual educational environments. Nevertheless, a number of relevant related questions arise as research opportunities: (1) Do students really improve their performance (understood as learning better or developing better skills) in the course thanks to virtual teaching assistants? (2) Do teachers really reduce their workload by not having to answer so many questions (being able to devote the time gained, for example, to improve the course content)? (3) Can these isolated experiments be repeated in other learning contexts, with different student populations and in other areas of knowledge? (4) Are teachers aware of how the technology that helps them really works? (5) What are the ethical implications of using a virtual teaching assistant to support students in a course discussion forum?

VII. Education 4.0

The advent of this machine learning and deep learning education is strongly based (as for any other domain) on the availability of data [51]. Education 3.0, enabled by internet and cloud computing, shifted the focus from traditional face-to-face settings to online environments. Additionally, such online environments facilitate data gathering and collection, and therefore decision making based on analytics. As the availability of data is one critical factor for training the learning models on which education 4.0 is based, it is no wonder that most research initiatives and efforts have been focusing on online environments, with particular attention to MOOCs, but also to learning management systems or intelligent tutoring systems.

In contrast, little attention has been paid to bringing the data-driven perspective into face-to-face and blended learning environments. As discussed in previous sections, intelligent support for content adaptation, collaboration and interaction, etc. are emergent research areas with plenty of activity in the literature for the online context. However, we believe that such processes in face-to-face and blended learning environments can also benefit from the tools developed for and the lessons learned from the online world.

Nevertheless, important challenges arise which jeopardize such application. The difficulties related to gathering data in a context which is not usually mediated by technology are the most immediate ones. An additional potential problem can be the volume of data, given that online educational settings tend to be more massive than face-to-face ones. Fighting these challenges should be the next step for closing the loop and bringing the education 4.0 technologies back into the traditional educational context.

VIII. Conclusion

Although technological progress is continuous and at different fronts, from a conceptual point of view it is good to identify milestones to have a grand view of the state of the art. We have identified 4 revolutions in education following the industry 4.0 example. We start with the *oral education* (Education 0.0) and move to the *documented education* (Education 1.0) after the invention of the printing press. The second revolution of electronics and telecommunications brings us to the *audio-visual education* (Education 2.0). The third is the *connected education* (Education 3.0) on the basis of internet and connected devices. Education 4.0 with natural interfaces and deep learning technology would be the *smart education*. The existence of advanced technologies does not mean that we cannot use tools from earlier times. On the contrary, the new developments enrich the status quo giving us more possibilities to design rich educational experiences.

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