Robotics in the Classroom: Hopes or Threats?

Pierre Léna

Contents

Abstract

Artificial intelligence implemented in a great diversity of systems, such as smartphones, computers, or robots, is progressively invading almost all aspects of life. Education is already concerned by this revolution, as are medicine or care for elderly people. Education is indeed a special case, because it is fundamentally based on the relationship, involving love and emotions as well as knowledge, between a fragile child and an adult. But teachers are becoming rare and education expensive: The Earth demography is here an economical challenge. We examine some of the various modalities of teacher substitution, companionship or computer-resources which are already experimented, and discuss their ethical aspects. We conclude on the positive aspects of computer-aided education, which does not substitute the teacher, but may help and provide continued professional development.

Keywords

Education · Emotions · Children · Adults · Love · Knowledge relationship · Robots

Introduction

In 2017, Sir Anthony Seldon, specialist of education, vice-Chancellor of the University of Buckingham (UK), prophesized that within a decade: "... intelligent machines that adapt to suit the learning styles of individual children will

P. Léna
Observatoire de Paris & Université de Paris, Paris, France
e-mail: pierre.lena@obspm.fr

Pontifical Academy of Sciences & Fondation La main à la pâte, Paris, France

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soon render traditional academic teaching all but redundant [. . .]. They will learn to read the brains and facial expressions of pupils, adapting the method of communication to what works best for them" (Bodkin 2017). As the digital world, supported by the seemingly endless developments of artificial intelligence, data collection and mining, progressively invades all sectors of private and public life, will education resist to this invasion, or benefit from it? Indeed, since over two millennia, schooling has been based on a face-to-face relation between a teacher and the student. Will robotics make outdated this traditional vision, at an epoch when the amount of mass education is required on Earth at an unprecedented scale? Is this perspective a fantasy, a likely nightmare or an interesting evolution?

First, we discuss in general terms the hopes and changes which these perspectives could offer, while having been explored since barely a decade. Second, we address the simplest issue, dealing with the use of robots as pedagogical tools, with the specific goal to introduce the pupils to computer science. Third, we enter into the hot question of "robot teachers," analyzing the diversity of situations and current experiments and research which can be considered under such a broad and somewhat provocative expression associating "teachers" and "robots": it may span from a simple machine, designed to help a human teacher, to a full humanoid substitute of the teacher. At this point, it is necessary to introduce an ethical discussion, since one must consider the fragility of the child, exposed for instance to the possibility for a robot "to read the child's brain and face." Finally, we try to focus on the most promising and probably most realistic contribution of artificial intelligence to education, namely the computer-aided education, understood in a less revolutionary sense than the existence of humanoid robot teachers.

We shall observe that actual implementations to-date are only beginning, and research on their impacts very limited. Hence, our conclusions will be careful and probably fragile.

Emerging Needs, Hopes, and Threats

Since over two millennia, education at school is based on a face-to-face relation between the teacher and the student. The person-to-person dialog between Socrates and Menon happens today in classes at a different scale, with tens, hundreds, or even more pupils in the class, but a "vertical" transmission of knowledge remains the general rule of primary and secondary education. Worldwide, teachers are trained for this purpose and implement their pedagogy in this context. Is this the most efficient way to transmit knowledge and to prepare the youth to read the present world and be ready for its future? Various attempts to explore alternate ways of improvement have been made, based on more or less empirical hypothesis on the learning process. Since several decades and following John Dewey's ideas (1859–1962), an *inquiry* pedagogy, more "horizontal" and making the students more active, has developed. Neurosciences developments with Stanislas Dehaene are supporting the early intuitions of Maria Montessori (1870–1952), Lev Vygotski (1896–1934), and Jean Piaget (1896–1980), for a better respect of the stages which characterize the cognitive and physical development of the child (Dehaene 2018). Our own effort since 1996 on early science education with *La main à la pâte* has been inspired by these pedagogies (Charpak et al. 2005).[1] Recently, the scheme of "flipped (or inversed) classroom" (*classe inversée*) has become popular and begins to be implemented in various countries,[2] especially in higher education. There, the autonomy of the learner is stimulated, while the teacher is considered as a support, answering the questions and leading discussions.

Breaking the passivity of the "purely listening" (and often bored!) student is considered essential for an efficient learning of a foreign language: hence language laboratories have been among the first to replace, for some activities, the teacher by a machine. More recently, computers and tablets have emerged in the classrooms as teaching aids, and specific software becomes available to teachers of all disciplines. Geometry benefits from visual tools, geography from Google Earth, language from orthographic correction and voice helpers, etc.

With the advent of the digital revolution, progressively impacting all sectors of human activities and professional practices, an unescapable question emerges: will teachers disappear, or have to adapt to completely new schemes of professional activity? The physician profession is interesting to observe. In its practice, the personal relation with the patient, as for teachers, has always been considered essential. Yet, the profession is currently confronted to this same question and already encounters significant evolutions, such as telemedicine, robotics helpers . . . Similarly, the magnitude of aging population in China or Japan already leads to some care-taking robots for old people, a case which is not without some similarities with the issue of teaching.

Some relatively significant impacts on classroom practices are already perceivable: students have an unlimited access to information through Internet; collaborative work between schools across a country, or even worldwide, becomes common practice, especially on universal issues like sustainable development or climate education;[3] special education for children with dyspraxia draws on digital resources,[4] etc.

[1] See also (in English) www.fondation-lamap.org

[2] https://en.wikipedia.org/wiki/Flipped_classroom

[3] For example the networks organized by various organisations such as *La main à la pâte*, *Scholas Occurentes*, *Eco-schools*, etc. (see Battro et al. 2017).

[4] In France, inspired by S. Dehaene, the 'Cartable fantastique' (*The fantastic schoolbag*) https://www.cartablefantastique.fr/

Looking further into the future, several factors may indicate that a massive evolution of the classical schooling methods may come or will even be forced to happen. The cost of education may be the dominant factor. In a developed country such as France, the current offer of primary and secondary education—up to ages 16–18—to the whole of an age class represents over 10% in the budget of the nation. The goal of "*equal access to quality education*" is included as one of the 17 Sustainable Development Goals of the United Nations,[5] promulgated in 2015. Yet, attaining worldwide this goal seems entirely out of prospect during the next decades. It would need adding 20.1 million primary and secondary school teachers to the workforce, while also finding replacements for the 48.6 million expected to leave until 2030, because of their retirement, or the end of a temporary contract, or the desire to pursue a different profession with better pay or better working conditions (UIS 2016).[6] On top of the costs themselves, which yet maintain mediocre salaries for teachers, the supply and quality of these teachers remains a central problem, almost everywhere. In France, the traditional status of public teachers as selected "expert" civil servants is no longer sustainable for mathematics or English teachers in secondary schools, and other schemes of recruitment, with a lesser guarantee on quality, are being implemented. In Africa especially, the demographic pressure in the coming decades is preparing a difficult challenge for schooling, which itself is a necessary condition for economic development and adaptation to climatic changes. Therefore, in developing countries, if cheaper methods, such as lessons through Android smartphones, become available to access the knowledge, it is likely that the poorest parents will use the cheapest means, while families with sufficient resources will continue to choose human teachers for their children whenever possible. The universal extension of Wi-Fi connections, with local substitutes, in case of unavailability, which are capable to store large data bases, creates an entirely new context, not free of commercial interests.

It is therefore worthwhile to explore more in depth the perspectives which robotics and computers may offer to these challenges. Moreover, observing how schooling is becoming a business in some developing or emerging countries, the commercial potential of education needs, if seized by actors mastering the digital tools at large scale, may become a reality, with all the questions it raises on quality, equity, and ethics.

People seem to be worried about the use of robots in schools. In 2012, a European survey of public attitudes (European Commission 2012) to robots over 27,000 persons reached interesting conclusions. In great majority, European citizens are not opposed to the use of robots, in case of manufacturing or various domestic uses. On the opposite, 60% consider that robots should be banned from the care of children, 34% that they should be entirely banned from the field of education, while only 2% thought robots could be used in education, namely schooling. Similar attitudes are observed towards health care, care of children, elderly, or disabled persons, i.e., human tasks. Either pros or cons, are these attitudes justified?

We place the present discussion in a slightly broader frame than the mechanical robots and extend it to the possible roles of computer-based artificial intelligence in education. Indeed, there exists a continuum from the latter to the former, and technology is constantly opening new combinations of soft- and hardware. As a matter of fact, the term "computer aided education" goes beyond "robotics" itself (Cigi 2013). This broad frame may be addressed with the goal to totally or partially replace the teachers by robots, a discussion well introduced by Amanda Sharkey (2016), from whom we borrow several points, referring to her abundant and up-to-date bibliography.

A Simple Case: Robots as Pedagogical Tools

In primary and secondary schools, science and technology lessons are already exploiting robotics as a rich pedagogical tool. Since 2008, the robot Thymio II,[7] developed at the Ecole Polytechnique Fédérale in Lausanne (Switzerland), provides a combination of robotics and programming, in order to introduce children to the digital world. *La main à la pâte* in France has developed extensive modules, named "*1, 2, 3 . . . Codez*" helping primary school teachers to introduce robotics, from age 5 upwards.[8] These modules, introduced in 2014, are disseminated with a great success among teachers. Observing teachers and children in the thousands of classes which are using worldwide these teaching aids,[9] some interesting conclusions are reached:

- First, children at all ages find robots attracting and exciting their curiosity.
- Young children progressively learn the difference between "alive" and "not-alive," comparing the robot with animals or plants. Qualifying the robot as "intelligent" and having themselves programmed it, they explore the meaning of human intelligence.
- Programming a robot for a specific task, then letting it act, explores the benefits of mistakes and errors, without

[5] https://sustainabledevelopment.un.org/

[6] 'Education for people and the planet', UNESCO 2016.

[7] https://www.generationrobots.com/en/179-educational-robot-thymio

[8] Free modules available in English, German and French: http://www.fondation-lamap.org/fr/node/65695

[9] See http://www.fondation-lamap.org/fr/page/34536/1-2-3-codez-espace-enseignants

any value judgment or cognitive risk for the student. As machine learning, it can be repeated at no cost and introduces the teacher to the use of more sophisticated machine learning if so wished.
- Equally interesting is the combination offered there between a physical object (the robot) and a logical set of instructions (the program). The former is submitted to the constraints of the physical world (e.g., the size of the room where the robot moves, the friction on its wheels, the battery . . .), while the latter is only constrained by logics and eventually mathematical rules. The fertile difference between an error and a physical approximation or uncertainty may then be introduced to students.
- Programming the robot offers an introduction to encoding with a rich combination of variables, sequences, programming events, and feedback. This is a first and early introduction to computer science. Some ethical aspects may also be introduced and discussed in the classroom: who should make a decision, the machine or the child?

To conclude this point, the use of robotics in classroom, combined with computer science and eventually electronics, is a straightforward and creative way to teach technology within the aggregate called STEM (Science Technology Engineering Mathematics).

Robot Teachers: A Diversity of Possible Roles?

Education among humans, as among some species within the animal world, begins with imitation. In parallel with imitation, a person-to-person relationship is established, which begins at the infant stage with the use of symbolic language. The act of teaching, its specific characters when exercised by humans, the complex interactions between the mind of the teacher and one of the pupils have been extensively studied, and cannot be developed here (Ziv et al. 2016; Strauss 2016). In principle, the question of an eventual "robot teacher" should be analyzed within this extremely complex context, especially when it is proposed to replace human teachers by a humanoid robot, which would fully handle the classroom.

As a first-order approach, I here follow the categories introduced by Sharkey (2016), who distinguishes: (a) the "social" robots as a substitute for teacher; or (b) as "a companion and peer"; or finally (c) as a tool for distance learning with telepresence. Each of these roles deserves a specific discussion, based on the few published experiences available today. We shall conclude that considering artificial intelligence (AI) as a potential teaching aid, rather than a full teacher substitute, seems to be the best direction to explore and implement, as argued by Rose Luckin and coworkers from University College London (Luckin et al. 2016). We observe that such categories, although helpful to sort out the diversity of uses and their positive or negative aspects, do not properly cover the great versatility of robots for many types of applications. The *NAO* robot, initially developed in France and currently in Japan,[10] seems to be used in many different instances: companion, game partner, attendance of a sick person, education, teaching aid for disabled, etc.

Robots as a Full Substitute to Teachers

Saya is a female humanoid robot developed in Japan. Its facial mobility allows to express emotions (anger, joy . . .). The techniques are similar to the ones developed for sexual robots (Levy 2007),[11] of which there already exist some presentations on Internet. Using robots to replace teachers in the classroom would require demonstrating the necessity and efficiency of such decision. As Sharkey notes, robots can be useful when special risks are affecting tasks carried by humans, such as dangerous environments or need for very fast decisions. Teaching is free of such risks. The heart of a positive interaction between the teacher and the student lays in the ability of the former to "read the mind" of the latter, hence to efficiently accompany the emotions as well as the acquisition of knowledge and know-how. Sharkey also argues that there exist to date no evidence showing that a robot, acting "alone" as a full teacher's substitute, can better understand what happens in the children's mind. Research may clarify this point in the future.

Many jobs done by humans today are transformed into robotics tasks for economic reasons, provoking at least temporarily an employment crisis, without a compensating creation of jobs. Would a similar evolution be conceivable for the teaching profession, which suffers from a recruitment crisis in many countries? At the moment, the available evidence does not show that robots could outperform humans in a teaching role, neither that they would be cheaper than a teacher.

Robots as Companions for Learning

As a fully humanoid teacher seems a fantasy at the moment, some tasks in the classroom could nevertheless evolve, by using robots with a gradation in complexity and interactivity. We mention *Elias Robot* for young learners, focused on language acquisition and based on the already mentioned humanoid *NAO*, which today appears as the most

[10] The French designed *NAO* robot has been sold to the Japanese company SoftBank Robotics in 2016: https://www.softbankrobotics.com/emea/en/nao. See also https://fr.wikipedia.org/wiki/NAO_(robotique)

[11] See also https://fr.wikipedia.org/wiki/Robot_sexuel

advanced robot for classroom. *Elias* is being tested in Finnish schools (Reuters 2018). In Chinese kindergarten, the semi-humanoid robot *Keeko* is used "to help children solve logical problems."[12] Another robot, *Tega*, is so described: "A smartphone-based robot, *Tega* serves as a classroom learning companion for younger kids. The interactive robot asks students to complete tasks, monitors their success, and provides feedback. *Tega*'s shape and skin mimics that of a stuffed animal, which many young students find appealing and non-threatening" (Lynch 2019).

The *Avatarmond iPal Robot* family is advertised as follows: "Under the supervision of a teacher, iPal can aid in lessons by presenting educational content in an engaging manner that supports social development and encourages interest in science and technology" (Nanjing AvatarMind Robot Technology 2017).

Two English-speaking *Robovie* robots have been tried in a Japanese elementary school, interacting with fifth and sixth grade pupils. The children wore an RFID tag, allowing the robot to identify them (Kanda et al. 2004). A further experiment, done by the same team, simulated attachment, progressing with time, of the robot to individual students. In this experiment the robot would learn some particularities of a child, like the name, or give him a "secret."

Another experiment has been reported in an English language school for Japanese children, with the idea that children would attach to the robots and be able to actively teach some verbs to them (Tanaka and Matsuzoe 2012). The reported gain in efficiency is not clear.

Irobi, made in South Korea and very successful in Asia, is a 7 kg semi-humanoid robot, Palk (2010) explains: "For children, *Irobi* is like a nanny. It speaks (1000 words), sings, expresses feelings by its movements. It can learn English." *Engkee* is a robot "teacher" for English lessons, implemented in South Korean classrooms since 2010.

The European Commission has been supporting a research program (2016–2018) named Second Language Tutoring Using Social Robots.[13] Initiated in the Netherlands, it provides students with a "companion robot" (Fig. 1), in order to help language acquisition, especially for immigrant Turkish population.

All these systems would deserve detailed research to understand their potential effects, but one cannot escape the feeling that, by resembling sophisticated dolls rather than humans, they are based on a quite naïve vision of the child's relation to other children.

At the university level with much older students, the robot *Jill*, based on IBM's Watson system (open multicloud platform), has been developed by the Georgia Institute of Technology to teach a graduate course online throughout the world. *Jill*'s creator Ashok Goel observes that the students, at least in the beginning, did not even notice they were dealing with a robotic teaching assistant (TA). Here is the analysis, possibly over-optimistic, given by Tim Sprinkle 2017, from the American Society of Mechanical Engineers: "Jill was an incredibly effective teaching assistant. She answered student questions within minutes, no matter when they contacted her. She offered in-depth answers to a wide range of complex queries. She was generally more accessible, more personal, and more upbeat than any human could ever be. The class rolled through half a semester before Goel gave up Jill's real identity. Since then, he's used the AI system in a few other classes and has noticed that, beyond helping with his workload, Jill also improves the overall student experience, making for better, more effective, and more engaged learning."

Telepresence and Teaching

Within the continuum between full substitutes and aided teaching, the telepresence robots represent an intermediate step, in the sense that they are operated by humans—students or teacher—at a distance, to interact with a remote classroom. In Korea, the *EngKey* robot is being used for distant English lessons. An experiment has been made to remotely help teachers in the Philippines, in order for them to teach their South Korean students.

One may question whether this is more efficient than a straight Skype communication with the teacher telepresence?

Robots in Special Education

Robots could be considered as a kind of "exoskeleton," where disabilities which may hinder an access to education, would be helped by the use of a robot (Virnes 2008). The above-mentioned *NAO* robot is used to help Alzheimer patients or educate autist children.

Ethics and Teacher Substitutes

When facing the endless blossoming of robotic technologies, the way their apparently costless or cheap access is developing along a new and often hidden capitalistic model, when observing their potential impact on education, the words of Pope Francis in the Encyclical Letter *Laudato Si'* come to mind. After reminding that "*it is right to rejoice in these advances* [of technical prowess] *and to be excited by the immense possibilities which they continue to open up before*

[12] See https://www.youtube.com/watch?v=jppnAR1mtOw

[13] See EU Commission Horizon 2020 Research project L2TOR: http://www.l2tor.eu/. This site offers a rich and recent bibliography of the research findings.

Fig. 1 A child with a L2TOR companion robot

us [102]," Francis, quoting Romano Guardini's book The End of the Modern World, warns on the "ironclad logic" of technology: "*The effects of imposing this model on reality as a whole, human and social, are seen in the deterioration of the environment, but this is just one sign of a reductionism which affects every aspect of human and social life. We have to accept that technological products are not neutral, for they create a framework which ends up conditioning lifestyles and shaping social possibilities along the lines dictated by the interests of certain powerful groups. Decisions which may seem purely instrumental are in reality decisions about the kind of society we want to build*." And later: "*Isolated individuals can lose their ability and freedom to escape the utilitarian mindset and end up prey to an unethical consumerism bereft of social or ecological awareness* [219]."

Using a different tone, Ashok Goel, quoted by the American Society of Mechanical Engineers (Sprinkle 2017) and already mentioned above with his robot *Jill*, recognizes the need to personalize all the tutoring and teaching: "*to get there, technology* [i.e. *Jill* and other robots] *needs to become more human*". What does it mean for education, in order to remain human?

In her excellent paper, Sharkey develops an in-depth analysis of the ethical concerns about robot teachers, covering the various uses mentioned above (Sharkey 2016).

- First, she discusses the threat to privacy, with robots exerting personal surveillance, collecting personal data on children, monitoring teacher performance or classroom activities. To assess performance of children, emotions could be assessed with various sensors, measuring facial expressions or physiological reactions. The results may be used without control of the parents or imposed on them as criteria for judging their child's behavior. When undertaken with research aims, such actions could be done with adequate ethical protocols,[14] but their generalization may easily turn into a "Panopticon" to control the classroom and even to provide data for commercial production of educational material. Telepresence robots may even convey data escaping from the country where they act.
- Second, Amanda Sharkey analyses the illusion or rather the postulate, which assumes that a robot is able to relate to humans. She discusses the attachment and deception children may encounter when, dealing with robots, they loss real human contact. The concept of *uncanny valley* seems appropriate here, as it is depicting the emotional response of humans to an object which appears more or less undistinguishable from the reality of a human person.[15] Exposing children to the robot *NAO* and others, Kimberly Brinks (Living Lab Program, University of Michigan) has explored how 240 youngsters, age 3–18, eventually trust a robot and feel at ease (Kim 2018; Brink et al. 2017).
- Third, the question of control and accountability is addressed. If a robot takes, partially or totally, the role of a teacher, it would have to exert such functions as authority, empathy, reward, and eventually punishment. How would children react to such behaviors coming from a machine? how far would the machine be "authorized" to act?

  Similar questions may emerge on the robot-soldier. Some arguments are given in favor of its use, claiming that a robot behavior might be more "ethical" than human reactions (?).

[14] Key Laboratory for Child Development and Learning Science, Nanjing (China). During the period 2005–2015, this laboratory has carefully developed a research protocol to measure young student's emotions while learning in the classroom.

[15] The long discussion appearing in the following reference shows the actuality of this concept, in light of the efforts of technology to 'become more human'. See: https://en.wikipedia.org/wiki/Uncanny_valley

It is worth quoting here Chrystof Heyns, the United Nations special rapporteur on extrajudicial, summary or arbitrary executions. He argues against the use of autonomous robots to make lethal decisions on the battlefield. His reasoning is that robots "lack human judgement, common sense, appreciation of the larger picture, understanding of the intentions behind people's actions, and understanding of values and anticipation of the direction in which events are unfolding" (Heyns 2013). Several of these arguments apply as well to a robot-teacher, which would most likely lack the ability to understand the complexity of children behavior and moral background. In addition, even a good programming might not avoid all kind of biases which may lead to unequitable treatment of students (color of skin, accent and language, weak disabilities, parental and cultural heritage, etc.).

Similar questions may be raised for a companion robot, or for the telepresence robot, although in the latter case a human presence is making decisions at distance.

A Way for the Future: Computer-Aided Instruction

Analyzing the economical perspectives in developing countries confronted to the digital revolution, Jeffrey Sachs analyzes the key sectors of economy and lists the potential effects of this revolution. Considering education, he states: "Education [will see] a major expansion of access to low-cost, high-quality online education, including online curricula, online monitoring of student progress, online teaching training, "connected classrooms" via videoconferencing, and distance tutoring" (Sachs 2019, p. 162). Von Braun and Baumüller equally addresses education and knowledge as a domain where artificial intelligence and robotics could reduce poverty and marginalization (von Braun and Baumüller 2021, Chap. 7 this volume).

There is, and will be, a very broad range of ways to use algorithms and computers to help the learning process, complementing the classical face-to-face classroom or auditorium. All kinds of software,[16] some using artificial intelligence, are already available to help visualize the solving of mathematical problems, such as GeoGebra. Others are simulating phenomena in astronomy,[17] physics,[18] or chemistry.[19] Complexity of climate change is modeled in an accessible way to help teachers with lecturing or classroom discussions.[20,21] This use of software is an extremely rich field which rapidly develops, greatly helping teachers at all levels if they are properly trained to use these tools with a critical mind.

Massive Open On-line Courses (MOOC) represent another aspect of computer-aided education (Wikipedia last updated 2020). Although versatile in use, and able to ensure a broad dissemination, one should not underestimate their cost of development and monitoring. For example, the *Class'Code* MOOC offered in France since 2016 by the Institut national de recherche en informatique et automatique (INRIA), in cooperation with *La main à la pâte*, aims at students aged 8–16, in order to initiate them into the process of computer sciences (machines, algorithms, information, programs). This has to-date reached about 3000 students, for a non-negligible investment cost of about 2 M€, i.e., about 40 years of a teacher's salary cost in a developed country.

Websites offering "questions & answers" help to students, with typical exercises in science and mathematics, may replace traditional books with more progressive, case-adapted algorithms, such as the Socratic application, now offered by Google.[22]

Smartphones already exist with a variety of sensors and could accommodate more through USB connections. These can be used to collect data: simple applications use the smartphone accelerometer and can provide useful measurements of seismicity (app SEISME), others collect information on biodiversity (app PLANTNET) and there seems to be no limit on the development of such actions of participative science (Académie des Sciences 2018).

We are probably observing the emergence of a considerable diversity of learning tools, available on computers through Internet, but also through smartphones, of easy and free access, which can profoundly transform the teaching practice, especially for science lessons in poor areas where experimental material is rare.

Conclusion

In the classroom, the replacement of teachers by robots could be extremely diverse in its modalities, from full substitutes to teaching or learning companions. It is still in infancy and sufficient research of the impact is not yet available. The technical possibilities combining artificial intelligence and

[16] See https://listoffreeware.com/list-of-best-free-math-software/

[17] E.g. The Nebraska Astronomy Applet Project: https://astro.unl.edu/naap/

[18] E.g. https://listoffreeware.com/free-physics-simulation-software-windows/

[19] E.g. https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/simulations.html, from the American Chemical Society.

[20] See *Climate Change Policy Simulator C-Roads*, from the Massachusetts Institute of Technology. https://www.climateinteractive.org/tools/c-roads/

[21] See Software *SimClimat* (2019, in French): http://education.meteofrance.fr/lycee/animations/logiciel-simclimat-un-modele-simple-de-bilan-radiatif-de-la-terre

[22] See https://play.google.com/store/apps/details?id=org.socratic.android&hl=fr

teaching needs are probably immense, but the opportunities and costs of such investment remain today questionable. The ethical aspects of such developments raise many questions, to be explored in depth, since children are by essence extremely vulnerable human beings. Providing tools which better answer human expectations, especially those of students, is quite different from building a "conscious" robot which is designed *to be exactly like a human*.

Facing these limitations and words of caution, the needs to develop education worldwide are so pressing, and their cost implies such a small probability to be fully covered during this century, that any reasonable solution which benefits from these technological advances will become helpful, especially in the broad area of computer-aided education.

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