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COMMENTARY

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Inquiry and critical thinking skills for the next generation: from artificial intelligence back to human intelligence

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Abstract

Along with the increasing attention to artificial intelligence (AI), renewed emphasis or reflection on human intelligence (HI) is appearing in many places and at multiple levels. One of the foci is critical thinking. Critical thinking is one of four key 21st century skills – communication, collaboration, critical thinking and creativity. Though most people are aware of the value of critical thinking, it lacks emphasis in curricula. In this paper, we present a comprehensive definition of critical thinking that ranges from observation and inquiry to argumentation and reflection. Given a broad conception of critical thinking, a developmental approach beginning with children is suggested as a way to help develop critical thinking habits of mind. The conclusion of this analysis is that more emphasis should be placed on developing human intelligence, especially in young children and with the support of artificial intelligence. While much funding and support goes to the development of artificial intelligence, this should not happen at the expense of human intelligence. Overall, the purpose of this paper is to argue for more attention to the development of human intelligence with an emphasis on critical thinking.

Keywords: Artificial intelligence, Critical thinking, Developmental model, Human intelligence, Inquiry learning

Introduction

In recent decades, advancements in Artificial Intelligence (AI) have developed at an incredible rate. AI has penetrated into people's daily life on a variety of levels such as smart homes, personalized healthcare, security systems, self-service stores, and online shopping. One notable AI achievement was when AlphaGo, a computer program, defeated the World Go Champion Mr. Lee Sedol in 2016. In the previous year, AlphaGo won in a competition against a professional Go player (Silver et al. 2016). As Go is one of the most challenging games, the wins of AI indicated a breakthrough. Public attention has been further drawn to AI since then, and AlphaGo continues to improve. In 2017, a new version of AlphaGo beat Ke Jie, the current world No.1 ranking Go player. Clearly AI can manage high levels of complexity.

Given many changes and multiple lines of development and implement, it is somewhat difficult to define AI to include all of the changes since the 1980s (Luckin et al. 2016). Many definitions incorporate two dimensions as a starting point: (a) human-like thinking, and (b) rational action (Russell and Norvig 2009). Basically, AI is a term used to label machines (computers) that imitate human cognitive functions such as learning and problem solving, or that manage to deal with complexity as well as human experts.

AlphaGo's wins against human players were seen as a comparison between artificial and human intelligence. One concern is that AI has already surpassed HI; other concerns are that AI will replace humans in some settings or that AI will become uncontrollable (Epstein 2016; Fang et al. 2018). Scholars worry that AI technology in the future might trigger the singularity (Good 1966), a hypothesized future that the development of technology becomes uncontrollable and irreversible, resulting in unfathomable changes to human civilization (Vinge 1993).

The famous theoretical physicist Stephen Hawking warned that AI might end mankind, yet the technology he used to communicate involved a basic form of AI (Cellan-Jones 2014). This example highlights one of the basic dilemmas of AI – namely, what are the overall benefits of AI versus its potential drawbacks, and how to move forward given its rapid development? Obviously, basic or controllable AI technologies are not what people are afraid of. Spector et al. 1993distinguished strong AI and weak AI. Strong AI involves an application that is intended to replace an activity performed previously by a competent human, while weak AI involves an application that aims to enable a less experienced human to perform at a much higher level. Other researchers categorize AI into three levels: (a) artificial narrow intelligence (Narrow AI), (b) artificial general intelligence (General AI), and (c) artificial super intelligence (Super AI) (Siau and Yang 2017; Zhang and Xie 2018). Narrow AI, sometimes called weak AI, refers to a computer that focus on a narrow task such as AlphaZero or a self-driving car. General AI, sometimes referred to as strong AI, is the simulation of human-level intelligence, which can perform more cognitive tasks as well as most humans do. Super AI is defined by Bostrom (1998) as "an intellect that is much smarter than the best human brains in practically every field, including scientific creativity, general wisdom and social skills" (p.1).

Although the consequence of singularity and its potential benefits or harm to the human race have been intensely debated, an undeniable fact is that AI is capable of undertaking recursive self-improvement. With the increasing improvement of this capability, more intelligent generations of AI will appear rapidly. On the other hand, HI has its own limits and its development requires continuous efforts and investment from generation to generation. Education is the main approach humans use to develop and improve HI. Given the extraordinary growth gap between AI and HI, eventually AI can surpass HI. However, that is no reason to neglect the development and improvement of HI. In addition, in contrast to the slow development rate of HI, the growth of funding support to AI has been rapidly increasing according to the following comparison of support for artificial and human intelligence.

The funding support for artificial and human intelligence

There are challenges in comparing artificial and human intelligence by identifying funding for both. Both terms are somewhat vague and can include a variety of aspects. Some analyses will include big data and data analytics within the sphere of artificial intelligence and others will treat them separately. Some will include early childhood developmental research within the sphere of support for HI and others treat them separately. Education is a major way of human beings to develop and improve HI. The investments in education reflect the efforts put on the development of HI, and they pale in comparison with investments in AI.

Sources also vary from governmental funding of research and development to business and industry investments in related research and development. Nonetheless, there are strong indications of increased funding support for AI in North America, Europe and Asia, especially in China. The growth in funding for AI around the world is explosive. According to ZDNet, AI funding more than doubled from 2016 to 2017 and more than tripled from 2016 to 2018. The growth in funding for AI in the last 10 years has been exponential. According to Venture Scanner, there are approximately 2500 companies that have raised $60 billion in funding from 3400 investors in 72 different countries (see https://www.slideshare.net/venturescanner/artificial-intelligence-q1-2019-report-highlights). Areas included in the Venture Scanner analysis included virtual assistants, recommendation engines, video recognition, context-aware computing, speech recognition, natural language processing, machine learning, and more.

The above data on AI funding focuses primarily on companies making products. There is no direct counterpart in the area of HI where the emphasis is on learning and education. What can be seen, however, are trends within each area. The above data suggest exponential growth in support for AI. In contrast, according to the Urban Institute, per-student funding in the USA has been relatively flat for nearly two decades, with a few states showing modest increases and others showing none (see http://apps.urban.org/features/education-funding-trends/). Funding for education is complicated due to the various sources. In the USA, there are local, state and federal sources to consider. While that mixture of funding sources is complex, it is clear that federal and state spending for education in the USA experienced an increase after World War II. However, since the 1980s, federal spending for education has steadily declined, and state spending on education in most states has declined since 2010 according to a government report (see https://www.usgovernmentspending.com/education_spending). This decline in funding reflects the decreasing emphasis on the development of HI, which is a dangerous signal.

Decreased support for education funding in the USA is not typical of what is happening in other countries, according to The Hechinger Report (see https://hechingerreport.org/rest-world-invests-education-u-s-spends-less/). For example, in the period of 2010 to 2014, American spending on elementary and high school education declined 3%, whereas in the same period, education spending in the 35 countries in the OECD rose by 5% with some countries experiencing very significant increases (e.g., 76% in Turkey).

Such data can be questioned in terms of how effectively funds are being spent or how poorly a country was doing prior to experiencing a significant increase. However, given the performance of American students on the Program for International Student Assessment (PISA), the relative lack of funding support in the USA is roughly related with the mediocre performance on PISA tests (see https://nces.ed.gov/surveys/pisa/pisa2015/index.asp). Research by Darling-Hammond (2014) indicated that in order to improve learning and reduce the achievement gap, systematic government investments in high-need schools would be more effective if the focus was on capacity building, improving the knowledge and skills of educators and the quality of curriculum opportunities.

Though HI could not be simply defined by the performance on PISA test, improving HI requires systematic efforts and funding support in high-need areas as well. So, in the following section, we present a reflection on HI.

Reflection on human intelligence

Though there is a variety of definitions of HI, from the perspective of psychology, according to Sternberg (1999), intelligence is a form of developing expertise, from a novice or less experienced person to an expert or more experienced person, a student must be through multiple learning (implicit and explicit) and thinking (critical and creative) processes. In this paper, we adopted such a view and reflected on HI in the following section by discussing learning and critical thinking.

What is learning?

We begin with Gagné's (1985) definition of learning as characterized by stable and persistent changes in what a person knows or can do. How do humans learn? Do you recall how to prove that the square root of 2 is not a rational number, something you might have learned years ago? The method is intriguing and is called an indirect proof or a reduction to absurdity – assume that the square root of 2 is a rational number and then apply truth preserving rules to arrive at a contradiction to show that the square root of 2 cannot be a rational number. We recommend this as an exercise for those readers who have never encountered that method of learning and proof. (see https://artofproblemsolving.com/wiki/index.php/Proof_by_contradiction). Yet another interesting method of learning is called the process of elimination, sometimes accredited to Arthur Conan Doyle's (1926) in *The Adventure of the Blanched Soldier* – Sherlock Holmes says to Dr. Watson that the process of elimination "starts upon the supposition that when you have eliminated all which is impossible, that whatever remains, however improbable, must be the truth" (see https://www.dfw-sherlock.org/uploads/3/7/3/8/37380505/1926_november_the_adventure_of_the_blanched_soldier.pdf).

The reason to mention Sherlock Holmes early in this paper is to emphasize the role that observation plays in learning. The character Sherlock Holmes was famous for his observation skills that led to his so-called method of deductive reasoning (a process of elimination), which is what logicians would classify as inductive reasoning as the conclusions of that reasoning process are primarily probabilistic rather than certain, unlike the proof of the irrationality of the square root of 2 mentioned previously.

In dealing with uncertainty, it seems necessary to make observations and gather evidence that can lead one to a likely conclusion. Is that not what reasonable people and accomplished detectives do? It is certainly what card counters do at gambling houses; they observe high and low value cards that have already been played in order to estimate the likelihood of the next card being a high or low value card. Observation is a critical process in dealing with uncertainty.

Moreover, humans typically encounter many uncertain situations in the course of life. Few people encounter situations which require resolution using a mathematical proof such as the one with which this article began. Jonassen (2000, 2011) argued that problem solving is one of the most important and frequent activities in which people engage.

Moreover, many of the more challenging problems are ill-structured in the sense that (a) there is incomplete information pertaining to the situation, or (b) the ideal resolution of the problem is unknown, or (c) how to transform a problematic situation into an acceptable situation is unclear. In short, people are confronted with uncertainty nearly every day and in many different ways. The so called key 21st century skills of communication, collaboration, critical thinking and creativity (the 4 Cs; see http://www.battelleforkids.org/networks/p21) are important because uncertainty is a natural and inescapable aspect of the human condition. The 4 Cs are interrelated and have been presented by Spector (2018) as interrelated capabilities involving logic and epistemology in the form of the new 3Rs – namely, re-examining, reasoning, and reflecting. Re-examining is directly linked to observation as a beginning point for inquiry. The method of elimination is one form of reasoning in which a person engages to solve challenging problems. Reflecting on how well one is doing in the life-long enterprise of solving challenging problems is a higher kind of meta-cognitive activity in which accomplished problem-solvers engage (Ericsson et al. 1993; Flavell 1979).

Based on these initial comments, a comprehensive definition of critical thinking is presented next in the form of a framework.

A framework of critical thinking

Though there is variety of definitions of critical thinking, a concise definition of critical thinking remains elusive. For delivering a direct understanding of critical thinking to readers such as parents and school teachers, in this paper, we present a comprehensive definition of critical thinking through a framework that includes many of the definitions offered by others. Critical thinking, as treated broadly herein, is a multi-dimensioned and multifaceted human capability. Critical thinking has been interpreted from three perspectives: education, psychology, and epistemology, all of which are represented in the framework that follows.

In a developmental approach to critical thinking, Spector (2019) argues that critical thinking involves a series of cumulative and related abilities, dispositions and other variables (e.g., motivation, criteria, context, knowledge). This approach proceeds from experience (e.g., observing something unusual) and then to various forms of inquiry, investigation, examination of evidence, exploration of alternatives, argumentation, testing conclusions, rethinking assumptions, and reflecting on the entire process.

Experience and engagement are ongoing throughout the process which proceeds from relatively simple experiences (e.g., direct and immediate observation) to more complex interactions (e.g., manipulation of an actual or virtual artifact and observing effects).

The developmental approach involves a variety of mental processes and non-cognitive states, which help a person's decision making to become purposeful and goal directed. The associated critical thinking skills enable individuals to be likely to achieve a desired outcome in a challenging situation.

In the process of critical thinking, apart from experience, there are two additional cognitive capabilities essential to critical thinking – namely, *metacognition* and *self-regulation*. Many researchers (e.g., Schraw et al. 2006) believe that metacognition has two components: (a) awareness and understanding of one's own thoughts, and (b) the ability to regulate one's own cognitive processes. Some other researchers put more emphasis on the latter component. For example, Davies (2015) described metacognition as the capacity to monitor the quality of one's thinking process, and then to make appropriate changes. However, the American Psychology Association (APA) defines metacognition as an awareness and understanding of one's own thought with the ability to control related cognitive processes (see https://psycnet.apa.org/record/2008-15725-005).

Although the definition and elaboration of these two concepts deserve further exploration, they are often used interchangeably (Hofer and Sinatra 2010; Schunk 2008). Many psychologists see the two related capabilities of metacognition and self-regulation as being closely related - two sides on one coin, so to speak. Metacognition involves or emphasizes awareness, whereas self-regulation involves and emphasizes appropriate control. These two concepts taken together enable a person to create a self-regulatory mechanism, which monitors and regulates the corresponding skills (e.g., observation, inquiry, interpretation, explanation, reasoning, analysis, evaluation, synthesis, reflection, and judgement).

As to the critical thinking skills, it should be noted that there is much discussion about the generalizability and domain specificity of them, just as there is about problem-solving skills in general (Chi et al. 1982; Chiesi et al. 1979; Ennis 1989; Fischer 1980). The research supports the notion that to achieve high levels of expertise and performance, one must develop high levels of domain knowledge. As a consequence, becoming a highly effective critical thinker in a particular domain of inquiry requires significant domain knowledge. One may achieve such levels in a domain in which one has significant domain knowledge and experience but not in a different domain in which one has little domain knowledge and experience. The processes involved in developing high levels of critical thinking are somewhat generic. Therefore, it is possible to develop critical thinking in nearly any domain when the two additional capabilities of metacognition and self-regulation are coupled with motivation and engagement and supportive emotional states (Ericsson et al. 1993).

Consequently, the framework presented here (see Fig. 1) is built around three main perspectives about critical thinking (i.e., educational, psychological and epistemological) and relevant learning theories. This framework provides a visual presentation of critical thinking with four dimensions: abilities (educational perspective), dispositions (psychological perspective), levels (epistemological perspective) and time. Time is added to emphasize the dynamic nature of critical thinking in terms of a specific context and a developmental approach.

Critical thinking often begins with simple experiences such as observing a difference, encountering a puzzling question or problem, questioning someone's statement, and then leads, in some instances to an inquiry, and then to more complex experiences such as interactions and application of higher order thinking skills (e.g., logical reasoning, questioning assumptions, considering and evaluating alternative explanations).

If the individual is not interested in what was observed, an inquiry typically does not begin. Inquiry and critical thinking require motivation along with an inquisitive disposition. The process of critical thinking requires the support of corresponding internal indispositions such as open-mindedness and truth-seeking. Consequently, a disposition to initiate an inquiry (e.g., curiosity) along with an internal inquisitive disposition (e.g., that links a mental habit to something motivating to the individual) are both required

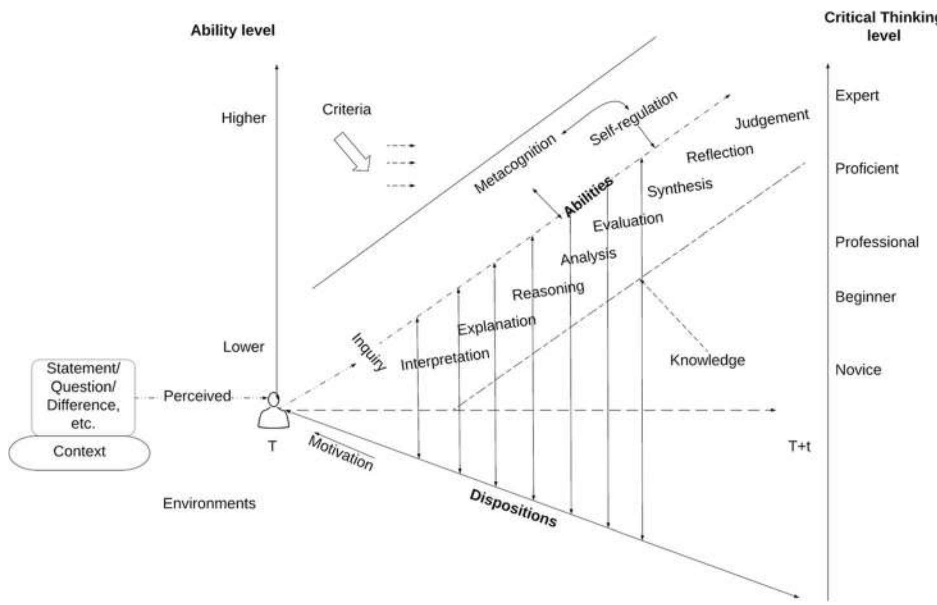

Fig. 1 A framework of critical thinking

(Hitchcock 2018). Initiating dispositions are those that contribute to the start of inquiry and critical thinking. Internal dispositions are those that initiate and support corresponding critical thinking skills during the process. Therefore, critical thinking dispositions consist of initiating dispositions and internal dispositions. Besides these factors, critical thinking also involves motivation. Motivation and dispositions are not mutually exclusive, for example, curiosity is a disposition and also a motivation.

Critical thinking abilities and dispositions are two main components of critical thinking, which involve such interrelated cognitive constructs as interpretation, explanation, reasoning, evaluation, synthesis, reflection, judgement, metacognition and self-regulation (Dwyer et al. 2014; Davies 2015; Ennis 2018; Facione 1990; Hitchcock 2018; Paul and Elder 2006). There are also some other abilities such as communication, collaboration and creativity, which are now essential in current society (see https://en.wikipedia.org/wiki/21st_century_skills). Those abilities along with critical thinking are called the 4Cs; they are individually monitored and regulated through metacognitive and self-regulation processes.

The abilities involved in critical thinking are categorized in Bloom's taxonomy into higher order skills (e.g., analyzing and synthesizing) and lower level skills (e.g., remembering and applying) (Anderson and Krathwohl 2001; Bloom et al. 1956).

The thinking process can be depicted as a spiral through both lower and higher order thinking skills. It encompasses several reasoning loops. Some of them might be iterative until a desired outcome is achieved. Each loop might be a mix of higher order thinking skills and lower level thinking skills. Each loop is subject to the self-regulatory mechanism of metacognition and self-regulation.

But, due to the complexity of human thinking, a specific spiral with reasoning loops is difficult to represent. Therefore, instead of a visualized spiral with an indefinite number of reasoning loops, the developmental stages of critical thinking are presented in the diagram (Fig. 1).

Besides, most of the definitions of critical thinking are based on the imagination about ideal critical thinkers such as the consensus generated from the Delphi report (Facione 1990). However, according to Dreyfus and Dreyfus (1980), in the course of developing an expertise, students would pass through five stages. Those five stages are “absolute beginner”, “advanced beginner”, “competent performer”, “proficient performer,” and “intuitive expert performer”. Dreyfus and Dreyfus (1980) described the five stages the result of the successive transformations of four mental functions: recollection, recognition, decision making, and awareness.

In the course of developing critical thinking and expertise, individuals will pass through similar stages which are accompanied with the increasing practices and accumulation of experience. Through the intervention and experience of developing critical thinking, as a novice, tasks are decomposed into context-free features which could be recognized by students without the experience of particular situations. For further improving, students need to be able to monitor their awareness, and with a considerable experience. They can note recurrent meaningful component patterns in some contexts. Gradually, increased practices expose students to a variety of whole situations which enable the students to recognize tasks in a more holistic manner as a professional. On the other hand, with the increasing accumulation of experience, individuals are less likely to depend simply on abstract principles. The decision will turn to something intuitive and highly situational as well as analytical. Students might unconsciously apply rules, principles or abilities. A high level of awareness is absorbed. At this stage, critical thinking is turned into habits of mind and in some cases expertise. The description above presents a process of critical thinking development evolving from a novice to an expert, eventually developing critical thinking into habits of mind.

We mention the five-stage model proposed by Dreyfus and Dreyfus (1980) to categorize levels of critical thinking and emphasize the developmental nature involved in becoming a critical thinker. Correspondingly, critical thinking is categorized into 5 levels: absolute beginner (novice), advanced beginner (beginner), competent performer (competent), proficient performer (proficient), and intuitive expert (expert).

Ability level and critical thinker (critical thinking) level together represent one of the four dimensions represented in Fig. 1.

In addition, it is noteworthy that the other two elements of critical thinking are the context and knowledge in which the inquiry is based. Contextual and domain knowledge must be taken into account with regard to critical thinking, as previously argued. Besides, as Hitchcock (2018) argued, effective critical thinking requires knowledge about and experience applying critical thinking concepts and principles as well.

Discussion

Critical thinking is considered valuable across disciplines. But except few courses such as philosophy, critical thinking is reported lacking in most school education. Most of researchers and educators thus proclaim that integrating critical thinking across the curriculum (Hatcher 2013). For example, Ennis (2018) provided a vision about incorporating critical thinking across the curriculum in higher education. Though people are aware of the value of critical thinking, few of them practice it. Between 2012 and 2015, in Australia, the demand of critical thinking as one of the enterprise skills for early-career job increased 125% (Statista Research Department, 2016). According to a survey across 1000 adults by The Reboot Foundation 2018, more than 80% of respondents believed that critical thinking skills are lacking in today's youth. Respondents were deeply concerned that schools do not teach critical thinking. Besides, the investigation also found that respondents were split over when and how to teach critical thinking, clearly.

In the previous analysis of critical thinking, we presented the mechanism of critical thinking instead of a concise definition. This is because, given the various perspectives of interpreting critical thinking, it is not easy to come out with an unitary definition, but it is essential for the public to understand how critical thinking works, the elements it involves and the relationships between them, so they can achieve an explicit understanding.

In the framework, critical thinking starts from simple experience such as observing a difference, then entering the stage of inquiry, inquiry does not necessarily turn the thinking process into critical thinking unless the student enters a higher level of thinking process or reasoning loops such as re-examining, reasoning, reflection (3Rs). Being an ideal critical thinker (or an expert) requires efforts and time.

According to the framework, simple abilities such as observational skills and inquiry are indispensable to lead to critical thinking, which suggests that paying attention to those simple skills at an early stage of children can be an entry point to critical thinking. Considering the child development theory by Piaget (1964), a developmental approach spanning multiple years can be employed to help children develop critical thinking at each corresponding development stage until critical thinking becomes habits of mind.

Although we emphasized critical thinking in this paper, for the improvement of intelligence, creative thinking and critical thinking are separable, they are both essential abilities that develop expertise, eventually drive the improvement of HI at human race level.

As previously argued, there is a similar pattern among students who think critically in different domains, but students from different domains might perform differently in creativity because of different thinking styles (Haller and Courvoisier 2010). Plus, students have different learning styles and preferences. Personalized learning has been the most appropriate approach to address those differences. Though the way of realizing personalized learning varies along with the development of technologies. Generally, personalized learning aims at customizing learning to accommodate diverse students based on their strengths, needs, interests, preferences, and abilities.

Meanwhile, the advancement of technology including AI is revolutionizing education; students' learning environments are shifting from technology-enhanced learning environments to smart learning environments. Although lots of potentials are unrealized yet (Spector 2016), the so-called smart learning environments rely more on the support of AI technology such as neural networks, learning analytics and natural language processing. Personalized learning is better supported and realized in a smart learning environment. In short, in the current era, personalized learning is to use AI to help learners perform at a higher level making adjustments based on differences of learners. This is the notion with which we conclude – the future lies in using AI to improve HI and accommodating individual differences.

The application of AI in education has been a subject for decades. There are efforts heading to such a direction though personalized learning is not technically involved in them. For example, using AI technology to stimulate critical thinking (Zhu 2015), applying a virtual environment for building and assessing higher order inquiry skills (Ketelhut et al. 2010). Developing computational thinking through robotics (Angeli and Valanides 2019) is another such promising application of AI to support the development of HI.

However, almost all of those efforts are limited to laboratory experiments. For accelerating the development rate of HI, we argue that more emphasis should be given to the development of HI at scale with the support of AI, especially in young children focusing on critical and creative thinking.

Conclusion

In this paper, we argue that more emphasis should be given to HI development. Rather than decreasing the funding of AI, the analysis of progress in artificial and human intelligence indicates that it would be reasonable to see increased emphasis placed on using various AI techniques and technologies to improve HI on a large and sustainable scale. Well, most researchers might agree that AI techniques or the situation might be not mature enough to support such a large-scale development. But it would be dangerous if HI development is overlooked. Based on research and theory drawn from psychology as well as from epistemology, the framework is intended to provide a practical guide to the progressive development of inquiry and critical thinking skills in young children as children represent the future of our fragile planet. And we suggested a sustainable development approach for developing inquiry and critical thinking (See, Spector 2019). Such an approach could be realized through AI and infused into HI development. Besides, a project is underway in collaboration with NetDragon to develop gamified applications to develop the relevant skills and habits of mind. A game-based assessment methodology is being developed and tested at East China Normal University that is appropriate for middle school children. The intention of the effort is to refocus some of the attention on the development of HI in young children.

Abbreviations

AI: Artificial Intelligence; HI: Human Intelligence

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Authors' contributions

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