Learners as Extended Minds of the Digital Age[1]

Alexei Semenov[1][0000-0002-1785-2387] and Vladimir Kondratiev[2][0000-0002-9792-2698]

[1] Lomonosov Moscow State University, Leninskie Gory 1, 119991 Moscow, Russia
Axel Berg Institute of Cybernetics and Educational Computing, FRC CSC RAS, 44k2 Vavilova st., 119333 Moscow, Russia
Herzen State Pedagogical University, 48 Moyka Embankment, 191186 St. Petersburg, Russia
Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, 141701 Moscow, Russia
alsemno@ya.ru
[2] National Research University Higher School of Economics, Moscow, Russia
kondratjew239@gmail.com

Abstract. Humanity is going through one of the most important information revolutions, after the emergence of speech and writing – the revolution of Artificial Intelligence. It was foreseen by Lev Vygotsky and artistically described by Andy Clark and Michel Serres. This revolution brings with it an extremely rapid and radical extension of the human mind. The report examines necessary implications of this extension for education systems. Neglection of these implications cause dramatic decrease of effectiveness of learning and teaching as we see clearly in the Coronavirus epidemy. A key example of mathematics education is considered. Today it is oriented on pen-and-paper computational skills and memorizing geometrical theorems. This cause losing motivation to education of millions of kids. Using existing environments of computer-based algebra and dynamic geometry an extended human can develop computational thinking along with rigor reasoning, pre-adaptivity and interest to math. Priorities in math education including assessment should be shifted from accuracy and speed of hand calculations to sensitivity to feedback self-evaluation and ability to improve your work.

Keywords: information revolutions, revolution of Artificial Intelligence, extended human, extended mind, digital technologies in education, mathematics education, computational thinking, digital competence, digital literacy, digital ethics, digital culture.

1 What is extended human?

Changes in information technology have led to major cultural and intellectual revolutions in the history of humanity. It is conjectured [1] that the human – Homo Sapiens emerged miraculously about 500,000 years ago with abilities to think, observe, and

[1] Supported by the Russian Science Foundation, grants No. 17-11-01377, 19-29-14202.

Proceedings of the 4th International Conference on Informatization of Education and E-learning Methodology: Digital Technologies in Education (IEELM-DTE 2020), Krasnoyarsk, Russia, October 6-9, 2020.

learn. According to research [2], this version of the human had the ability to teach as well.

The first information revolution for humanity was the advent of a new information technology – speech 50–100 thousand years ago. This resulted in radical changes in the transmission and reception of information, teaching, and thinking as well. Around 4–6 thousand years ago, writing appeared. So, knowledge and teaching could be transferred over time and space. About 100 years ago, the third revolution of Artificial Intelligence started. For the purposes of this paper, it would make perfect sense to call artificial intelligence any automation of intelligent activity.

According to Vygotsky [3], "the use of artificial means, the transition to mediated activity, fundamentally changes all psychological operations, just as the use of tools, limitlessly, broadens the range of activities within which the new psychological functions may operate". This leads us to the idea that each new revolution extends the human mind radically. In the case of speech, the expansion is going through a development of speech apparatus. In the case of writing, it came with external media of different forms: stylus with a soft clay tablet, papyrus and reed brush, chalk and slate, etc. Vygotsky outlines his perspective [4]: "The following may serve as examples of psychological tools and their complex systems: language, different forms of enumeration and counting, mnemonics, algebraic symbolism, works of art, writing, schemes, diagrams, maps, blueprints, all sorts of conventional signs, etc." [5].

Douglas Engelbart, in his "Mother of All Demos" [6], was speaking on Augmenting Human Intellect on which Wikipedia [7] writes "Augmented intelligence provides extra support for autonomous intelligence and has a long history of success. Mechanical and electronic devices that function as augmented intelligence range from the abacus, calculator, personal computers and smartphones. Software, with augmented intelligence, provides supplemental information that is related to the context of the user." Dwelling on the changes up to the era of AI, Andy Clark [8], follows Vygotsky literally (presumably not being acquainted with the words of the latter): "Mind-expanding technologies come in a surprising variety of forms. They include the best of our old technologies: pen, paper, the pocket watch, the artist's sketchpad, and the old-time mathematician's slide rule. They include all the potent, portable machinery linking the user to an increasingly responsive world wide web. Very soon, they will include the gradual smartening-up and interconnection of the many everyday objects that populate our homes and offices… It is because our brains, more than those of any other animal on the planet, are primed to seek and consummate such intimate relations with non-biological resources that we end up as bright and as capable of abstract thought as we are." Further development of Vygotsky's and Clark's ideas is presented in [5].

The authors we quote did not mention musical instruments and music notation that definitely add to the range of technologies.

2 Extended human's learning

We believe that the most important question forming the future of education in the 21st Century is:

Do we teach the extended human schoolchild all the appropriated means of the digital world,

or

Do we teach our students while depriving them of all means available outside school?

To illustrate the consequences of the second alternative, we can take a look at many teachers in our schools this spring of Coronavirus. They were asking students to do their homework on paper, then to take pictures of all pages and send them via mobile phone. Teachers were printing the received pages, marking them with their red ink, scanning them, etc. The case of a teacher who checked 1100 homework pages in a week was reported in [9]. This is an enormous waste of time and contradicts the essence of digital communication between professionals producing a document. Firstly, because it does not allow teachers to make suggestions and comments in an effective way, as happens in professional communication. Secondly, it does not allow students to improve their work, using these suggestions and not spending much more time than needed.

We propose to focus upon the first alternative. We consider the learners and teachers as extended humans, optimally using digital means to achieve their goals. Today, a learner's mind is extended not only by a pen, notebook, watch and a calculator, but also by, for example, an automatic translator, access to the World Wide Web and other digital means, extraordinarily increasing the power of the human brain.

Today's system of educational goals, planned results, standards and programs should be addressed specifically to the extended minds of the student and the teacher.

We evaluate the quality of the educational system, taking this into account.

In the following table we sum up the outcomes serving the goals of certain epochs:

Table 1. The outcomes serving the goals of certain epochs.

Epoch	Outcomes
Feudal Age	Survival through submissiveness
Industrial Age	Development through labor efficiency
Digital Age	Digital literacy and computational thinking

Learning to be an extended human means to be aware of oneself within the digital infrastructure and to be able to use digital tools to achieve one's personal goals efficiently and effectively. This is digital literacy that extends to life-long learning, including the integration of new digital means in your extended mind. The naturally extended mind uses computational thinking. According to Jeanette Wing [10], computational thinking is a concept which involves solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science. Michel Serre interprets computational (algorithmic) thinking as follows [11]: "The objective, the collective, the technological, the organizational: today, these depend far more on this algorithmic or procedural cognition than the declarative abstractions to which philosophy, nourished by letters and sciences, has dedicated itself for more than two millennia".

What does it mean for a teacher to be 'digitally extended'? We are convinced that the key role of the teacher is to orchestrate continuous reciprocal causation in the classroom and in the digital environment. The concept of the extended human, for the teacher, starts with commenting on students' works, presented in digital form, and discussing with the students, using classroom recordings, originally implemented for school security, but now also used as a tool for enhancing their interaction in the classroom or on project work. In the future, more and more important, but routine, operations will be passed to 'intelligent agents', considered and respected as parts of the extended teacher's mind. The AI agents can indicate various types of errors in essays, recognize students' faces and voices in the records, transcribe records and extract critical cases of behavior, reaction, or interaction for the teachers' and students' consideration. Naturally, the agents' oral messages can be synthesized, based on the teacher's speech.

The important mission of the teacher, being a life-long learning extended human, is to inspire the student for their learning journey and join them in it.

3 School Mathematics of the digital era

It was worth fostering neatness, accuracy and computational skills in life and in teaching math 100 or 200 years ago. Today our life is different: knowledge economy needs, as the priority, sensitivity to feedback, debugging, agile-development. Applying terms of cybernetics, we can say that the key abilities of an individual of 21st century are adaptivity and even pre-adaptivity (see [12]). So, the priorities in math education have to be changed as well: we need more independent reasoning, readiness to solve completely new problems, ability to find and correct mistakes. "Moreover, what went wrong, namely the bugs, are not seen as mistakes to be avoided like the plague, but as an intrinsic part of the learning process" [13].

The main educational goals are to ensure that the students effectively master:

- modeling real world phenomena to solve real world problems,
- solving mathematical problems with computer tools, rational,
- logical reasoning and acting inside and outside mathematics.

The innate curiosity and adaptation mechanisms should be brought into play.

4 What do we have in schools?

The main problem of mathematics education in schools is the absence of understanding of the essence and the area of applicability of mathematical knowledge. This leads to a low level of mathematical competence, low performance in exams, inability to apply the mathematical tools in everyday life. Schoolchildren often ask themselves: "Do I actually need mathematics in my life?". The absence of a reasonable answer to this question causes an outright loss of interest for mathematics both as a school subject, as an area of knowledge and profession.

Mathematicians, when they solve a new research problem, freely exchange knowledge, using available means, including digital. At school, the collaborative solution of a problem becomes almost impossible due to ‘academic ethics’: solving problems in a limited time, limited resources and limited ability to interact with the world is a moral must. The child can develop a painful, learned helplessness, which plays a significant role in weakening interest in mathematics. This state of affairs significantly reduces the level of trust in teachers and respect for the school.

We profess that geometry teaches students how to think. Well, it could teach thinking, if they proved theorems on their own. Currently, they have to memorize somebody else's proofs, and it is not the best way to learn.

5 What is happening with math in extended learning?

The productive solution to these problems and a way out of this situation could be a conscious and purposeful formation of a psychological attitude of extended human to:

- experiment with mathematical reality, especially exploiting the visualization power of digital technology,
- solve research problems using all available means and resources, including digital tools and the help of, not only classmates, but also other experts, who are currently engaged in similar research issues,
- model the real world, with your extended mind, using all the power accumulated by centuries of math and decades of computing.

Dynamic geometry (see https://en.wikipedia.org/wiki/List_of_interactive_geometry_software) is an environment that is the full implementation of a powerful opportunity to experiment, to guess and discover a fact, to make hypotheses, obtain evidence – witness for it and then – to prove it. This is a classical way for scientific discovery. With hand drawing, you will almost never reach this in school. But dynamic geometry is really a paradise when used properly for:

- geometry constructions,
- transformational geometry,
- using coordinates and algebra in geometry – analytic geometry.

Computer algebra system (CAS) is an environment where you can graph any function and use the graph to check your analytic solution of an equation. You can also concentrate on modeling the real world and passing the obtained equations to the system (see https://www.computerbasedmath.org/). Before digital means we asked students to solve only contrived problems. For the extended mathematical mind, the whole paradigm of application of math is completely different. Not specifically chosen numbers, not ‘tractable’ equations are possible, but everything that we can express in formulas and find parameters, via measurement, have a solution. The problem is how good our model is and how well we can interpret the results. Of course, this is not 100% accurate but we believe it is a fine approximation that produces a proper attitude for learners. Even more, sometimes we cannot write any equation but can describe local rules of behavior for the system and model it, not analytically but numerically, discretely.

Digital environments of computer algebra systems and dynamic geometry provide the scaffolding for a child that allows them to work in the zone of proximal development. Algorithms to deal with mathematical objects can be invented, then taught to the computer by the child and then integrated to the child-extended mind and used when needed.

An important feature of mathematics is that it can provide a student with problems completely new for them personally. So, math is the royal road to preadaptation to uncertainty that we spoke of [12].

The work was supported by: Russian Science Foundation, grant number 17-11-01377 (A. L. Semenov, parts 1, 2 and 3), Russian Foundation for Basic Research, grant number 19-29-14202 (V. V. Kondratiev, parts 4 and 5).

References

1. Stringer, C., Galway-Witham, J.: On the origin of our species. Nature, 546(7657), 212–214 (2017).
2. Strauss, I.: Newly discovered 400,000-year-old school means humans are way older than we thought. Retrieved from https://www.fromthegrapevine.com/lifestyle/newly-discovered-400000-year-old-school-israel-qesem-cave, last accessed 2020/11/21.
3. Vygotsky, L. S.: Mind in society: The development of higher psychological processes. Harvard University Press (1980).
4. Vygotsky, L. S.: The instrumental method in psychology (1981), https://www.marxists.org/archive/vygotsky/works/1930/instrumental.htm, last accessed 2020/11/21.
5. Falikman, M. V.: Mir cifry: novye instrumenty razuma (Digital world: new instruments of the mind) [Conference presentation, in Russian]. https://www.psy.su/feed/8332/, last accessed 2020/11/21.
6. Engelbart, D. C.: The mother of all demos (1968), https://www.dougengelbart.org/content/view/209/448/, last accessed 2020/11/21.
7. Augmented learning, https://en.wikipedia.org/wiki/Augmented_learning, last accessed 2020/11/21.
8. Clark, A.: Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence. Oxford University Press (2003).
9. Abramov, D.: How we helped 900,000 schoolchildren and their teachers in the first month of quarantine [Blog post], https://habr.com/ru/company/skyeng/blog/503316/, last accessed 2020/11/21.
10. Juškevičienė, A., and Dagienė, V.: Computational thinking relationship with digital competence. Informatics in Education, 17(2), pp. 265–284 (2018).
11. Serres, M.: Petite Poucette, Éditions Le Pommier: (2012). Eng. Transl., Thumbelina: The culture and technology of millennials. Rowman & Littlefield (2014).
12. Asmolov, A. G., Shekhter, E. D., and Chernorizov, A. M.: Preadaptation to uncertainty as a navigation strategy for developing systems: evolutionary routes. Psychology, 4, 1–23 (2017).
13. Papert, S.: Mindstorms: Computers, children, and powerful ideas. Basic Books, New York (1980).