

# From STEM to STEAM: Toward a Human-Centered Education, Creativity & Learning Thinking

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## ABSTRACT

The 20<sup>th</sup> century was based on local linear engineering of complicated systems. We made cars, airplanes and chemical plants for example. The 21<sup>st</sup> century has opened a new basis for holistic non-linear design of complex systems, such as the Internet and air traffic management. Interconnectivity, communication and interaction are major attributes of our evolving society. But, more interestingly, we have started to understand that chaos theory may be more important than reductionism, to better understand and thrive on Earth. Systems need to be investigated and tested as wholes, which requires a cross-disciplinary approach and new conceptual principles and tools. Consequently, schools cannot continue to only teach isolated disciplines based on simple reductionism. *Science, Technology, Engineering, and Mathematics* (STEM) should also be integrated together with the Arts to promote creativity together with rationalization, and move (back) to STEAM (with an “A” for *Arts*). This concept shift emphasizes the possibility of longer-term socio-technical futures instead of short-term financial predictions that currently lead to uncontrolled economies. Human-centered design (HCD) can contribute to not only improving education technologies, systems and practices, but also as a discipline offering an integrated approach to learning by doing, expressing and critiquing, exploring possible futures, and understanding complex systems: HCD supports *learning thinking*.

## Author Keywords

Education; Creativity; Learning Thinking; Complexity; Human-Centered Design; Connectivity; Understanding; Cross-Disciplinary Approach; Orchestra Model.

## General Terms

Human factors; Education.

## ACM Classification Keywords

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## INTRODUCTION

The motivation of this essay is to introduce an open discussion on the transformation of education that could benefit new millennium learners and help them better integrate our constantly evolving socio-technical society. The claims and viewpoints presented here are based on my 35-year experience, both in industry and academia, in the fields of mathematics, automatic control, artificial intelligence, cognitive science, human-computer interaction and aerospace engineering. While developing the human-centered design Master’s and Ph.D. programs at FIT [1] and chairing the International Space University Team Project on “what space can contribute to global Science, Technology, Engineering, and Mathematics (STEM) education” [2], I realized the needs for transforming current university education contents and setups towards *learning thinking* in our new highly interconnected world. University education should of course be based on strong background constructed during primary and secondary education. This background should be better adapted to the technological means that we have today as well as the fundamental transformation and needs of our societal evolution.

*Learning thinking* is taken as a conceptual analog to *design thinking* [12] and more specifically learning by doing. In particular, the shift from the unidirectional show society to a virtual freely connected society requires new models where creativity (Arts<sup>1</sup>) and STEM disciplines can be integrated. It appears that in many countries worldwide, young people are less interested in science and engineering careers, i.e., what is now commonly called STEM in the United States. This seems to be a question of motivation (i.e., it is nowadays less rewarding to be an engineer mainly because it is less valued as before) and leadership. Standardization took the lead and individual technical engagement is not here anymore; conversely, business careers are more appealing because they appear to have a much better return on investment. Leadership should be goal-driven, directly related to human-centered possible socio-technical futures.

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<sup>1</sup> The polysemy of the term “Arts” may induce confusion. I use it here to denote disciplines that are mostly characterized by creativity such as graphical arts, music, dance, and humanities in general. Arts and Engineering are typically opposed, but it takes technical competence to be an artist, and artistic skills to be a great technician.

Let's try to analyze the potential influence of new technology in education, mainly information technology. We will then review the role of technology, focusing on the *connectivity* issue. The fact that our world is more interconnected increases the emergence of new patterns, properties and socio-cognitive attractors [7], in the chaos theory sense [16]. We are in this paradoxical situation where we live in a global society supported by the Internet, complex transportation systems and a worldwide economy, but we also have a need for humanistic "re-localization" of social practices. We need to better understand what this means for education purposes. How best to teach and what information is best? Is the traditional classroom setup valid anymore? Could everyone learn from home? What is the role of society in education in our tremendously interconnected socio-technical world? We are all different, and this variability needs to be addressed. We cannot and will not have a single model of learning where variations could be considered as noise. Learning models should thus be context-dependent. Each of us should be able to build his or her own model, but the foundation for those learning models needs to be further identified.

#### **KNOWLEDGE VERSUS UNDERSTANDING**

Our world has changed tremendously during the last twenty years. Nowadays, we cannot think without referring to an external device. Our *memory* is no longer limited to our brain; it is now augmented outside by our computer devices, which are themselves connected to the "cloud". Wow! Whenever we need information, we use our smart phone or tablet and get it immediately: "I get it now!" What a fabulous improvement in our lives! But, do we understand what we get? Montaigne said: we are better to have a "well-made rather than a well-filled head." [8] It is interesting to note that this statement was addressed to a large audience, such as what we find today on the Internet. Does this statement oppose *knowing and understanding*. Indeed, knowledge is useful, but only when adapting it to real world situations. We need to cultivate these adaptation cognitive functions that make knowledge vivid, useful and usable. Cognitive functions are defined in the context of human-computer interaction and automation as role, context and resources [4]. Today, since knowledge is both inside and outside our brains, it is time to rethink education and consider *intelligence as adaptation*. There was a time when the main goal of education was to prepare for societal life, to being contributors within society. Consuming television has turned us into spectators rather than contributors. Education of the twenty-first century should bring back this necessary capacity of knowing how, when and what to do to perform the ideal function in a given situation, including *communicating the right information to the right person at the right time*. This kind of capacity is an ultimate proof of intelligence. This is not new; Roger Schank already formulated this in the early eighties in his work on what he called "dynamic memory" [14].

This paper discusses *understanding* rather than *knowing*. Understanding is about utilizing skills and competence, and contextualizing deeper knowledge. It requires action to assimilate the right concepts, to put them in situation. This is why the notions of situation and context are so important. Young people must actively participate in doing things, in order to assimilate and accommodate information [10]. The adaptation cognitive processes that Piaget described are very useful for understanding this phenomenon. Piaget's theory is based on the concept of the schema, a cognitive entity that can be used to solve a problem and act on the environment. Assimilation is a process that uses an existing schema to deal with a new object or situation. Accommodation is the process of discovering a new object or situation that challenges an existing schema, which needs to be modified and sometimes drastically changed. Of course, Piaget concentrated his work on cognitive development and biological maturation; he did not explore culture and social influence on child development. We then need to refer to Vygotsky's work [17] on the role of social interaction in the development of cognition to better learn how cognition is incrementally situated (or contextualized) toward understanding. Today, quest for *meaning* is the key. We have more technology than we can afford to use or have time to understand at depth. It is time to make sense of this technology. What is it useful for? A good question is for example: how can we use the Internet in schools?

Learning by doing is not a new concept. This paper claims that *situated knowledge is designed*. This is why *Human-Centered Design* (HCD) developed in other domains, such as aerospace and computing systems, can be a good support to transforming, implementing and running education. A designer creates and refines a new object in the same way the artist returns to improve a painting or piece of music after new experiences have enriched the artist's perspective. Further, an artist's body of work evolves over his or her lifetime. This paper claims that we are all artists and designers of our own knowledge; therefore, it is time to restore *creativity* into education curricula. I believe that great people need to be great learning thinkers, in the sense of designers of their own situated knowledge. Further, *learning is a multi-agent activity*. Our social environment influences us, and in turn we influence our environment. Collaborative communities support learning thinking.

Today, our learning includes what we might call artificial agents, some new kinds of composite entities of people and systems. For example, writing this paper, I used my connection to the real world through the Internet; I watched movies, read journal articles, and even recent newspapers related to the topic of this paper in real time. It was like designing a new object, constantly supported by a virtual community of people. The challenge is always to maintain good *critical thinking*, not to be lost in a non-linear maze of hyperlinks, to keep focused on the points I wanted to make, selecting the right concepts, and so on. I imagined a student in the same situation, using this fantastic technology to

make his or her mind up on something important. This person is experiencing *situated knowledge design*. Of course, this kind of cognitive design process will only lead to successful results if experienced people in related field(s) of expertise evaluate it. Experience is not dry knowledge; it is situated knowledge, which has been used long enough and effectively to mean something in context. Experience is about meaning and action over time. It provides the foundation for understanding and it is the grounding within which situated knowledge is applied.

### THE ROLE OF TECHNOLOGY AND AUTOMATION

During the twentieth century, technology-centered engineering enabled the development of systems such as washing machines, cars, airplanes, nuclear power plants, computers and the Web. These objects were made using the same model, from science to engineering to customization, i.e., from means to purposes. These objects improved our way of life and changed our societal principles. We can no longer imagine today washing clothes in cold water outside during the winter; something I experienced not so long ago! Automation has prevailed and this is a good thing. It eliminated lots of repetitive and tedious tasks, freeing people to do more interesting things. Of course, it is not as simple as that. Automation also contributed to the obsolescence and creation of jobs and new practices. It has transformed the way we design and develop products. I will take two examples, the automobile industry and 3D printing.

The manufacture of vehicles began in the early twentieth century. Mechanical engineering, based on physics and mathematics, was an emerging discipline. Engines and body structures of cars were the most important pieces of work. Drivers were also mechanics. They needed to understand how to repair things on their cars. It took a long time for the emergence of drivers with no knowledge and understanding of car engine and body mechanics. Today, we can drive a car without (almost) any understanding of mechanics. This is because the car has reached a reasonable level of mechanical *maturity* that enables us to ignore it. Then, electronics and computers invaded the car, to the point that it is now impossible to repair a car without sophisticated diagnostic software. Electrical engineering and computer science took the lead over mechanical engineering. This shift in disciplines has necessary consequences on education.

It is interesting to notice that driving has become a topic of interest in the information technology industry. The Google self-driving car, for example, was recently developed. One of the most important issues is software reliability. Today, well-trained and experienced drivers ensure redundancy when something goes wrong. Computer science is now taking the challenge. Digital simulation is a great resource to test safety, efficiency and comfort. People are now able to test technology in simulation before anything is built. This is why HCD is taking the lead upon technology-

centered engineering today. New kinds of methods are emerging such as storyboarding, participatory design, scenario-based design, and formative usability evaluation. These expressive art forms existed before television, the digital age of animation and the technical age, as we currently know it to be. Human and social sciences are now combined with engineering techniques. *HCD is about creativity, innovation and critical thinking*. As Montaigne posited, these assets should be cultivated early on. This is why schools need to address cross-disciplinary approaches and practices at a very young age. Technology enables us to address this challenge. Visualization of complex shapes and processes is now possible. Technology enables to combine abstractions and concrete visual representations of real world objects and phenomena.

Computer-aided design (CAD) made tremendous progress during the last three decades, to the point that we can model a full virtual airplane, simulate it and use it (in simulation) to test it. Virtual but effective flight tests can be done before the airplane is built, is it not that fabulous? Why? This is because we understood fluid mechanics in detail, structural mechanics in detail, flight mechanics in detail, and electronics in detail. We have developed accurate simulation pieces of software that can now be combined to simulate the whole airplane. The design of the Falcon 7X by Dassault is a great example of the virtual concept revolution [5]. Of course, simulation does not negate real-world flight tests. In a similar way, the Google self-driving car still must be tested in real road and street traffic conditions.

We are now beginning to understand why and how the shift from mechanical engineering to information technology will modify the way we learn, work and live. 3D printing is another concrete example of this shift. CAD and software-based simulation opened the way; 3D printing now enables us to manufacture each piece of CAD-made equipment. Anyone can use a 3D printer. A few months ago, I received data from the Mars Science Laboratory (the now famous NASA Curiosity rover) that displayed a pyramidal rock, and I had this peculiar idea to 3D print it. It was like transmuting an object (the rock) from planet Mars to planet Earth! This technology could obviously improve the way geological practices could be done, but many other disciplines as well. Certainly 3D printing will also have repercussions on education content and practices.

For any designed material (including our example of automobiles), once a computing model is developed and tested, pieces can be 3D-printed at the full scale, assembled and physically tested. Consequently, technology enables us henceforth to be *contributing instead of consuming* [15]. This idea of shifting from knowledge consumption to socio-technical contribution is not only possible, but is also extremely motivating for young people [11]. We must begin using the technological tools of the 21<sup>st</sup> century now at the primary levels every day and in age-appropriate and

challenging ways to effectively prime students for increasingly complex use as they develop and mature as people. They must use these tools to contribute to collective projects that are meaningful and purposeful.

Therefore, technology can be used to empower people instead of diminishing their physical and intellectual capabilities. Automation contributes positively to societal advancement, and we need to make a distinction between mature versus evolving technology, more specifically transient states that we have known during the twentieth century (see the discussion on maturity of technology and maturity of practice in [1]). During the twentieth century, we were building the means and looking for purposes. Now, we have identified interesting purposes and must integrate the means because it is currently technologically possible.

### THE CONNECTIVITY ISSUE

We are infinitely more (technologically) connected than we have ever been. We are connected in space and time. Both the Web and transportation systems have drastically modified the concept of distance. We can be almost anywhere virtually in a few seconds, and physically there in a matter of minutes or hours. We can explore spaces that our ancestors could not even dream of reaching. This is due to automation. In a few minutes, I can book a trip on the Internet and go. In a few seconds using a computer application, I can interact live via video call with my daughter who lives in New Zealand, which is more than 13,000 kilometers away from Florida, where I live. I can fly to France in a few hours. All these connectivity possibilities have become cheaper because of automation. Compared to a century ago, many people today can choose how they want to live. Automation has freed them from basic tasks (technology as tools, e.g., washing clothes), and has enabled them to do things that were not possible before (technology as prostheses, i.e., flying).

Connectivity has increased the speed of our business. We accomplish more things than before. However, sometimes we also do things that are not necessary, mostly because technology is not mature enough. We can become slaves of technology, where instead technology should be our slave. To accomplish this, critical thinking is required, and consequently every student should engage in and be adept at critical thinking. Awareness of technology *limitations* and *capabilities* is crucial in this constantly evolving socio-technical world. In schools can we explore new uses of common technologies as a group, thus integrating human-centered design as a primary purpose and not only a means? What can we do? What is necessary of what we do and not do? These are practical and ethical questions that arise in our everyday life. Young people must be part of the discussion. For example, Skype, email and texting are very useful tools that enable us to connect wherever and whenever we want on this planet today. Should we use them to connect with someone in the next room? I would

like to think that this is a natural issue of maturity of practice that should be resolved in the near future. More generally, we have an abundant set of technological resources, and we need to learn how to use them. This is part of the challenge that *learning thinking* has to address.

What does it mean to be connected? Why is social connectivity so important? In the old Southwestern France countryside of my childhood, people were very interconnected. They had neither telephone, nor television, nor the Internet, but they had a remarkable network that could propagate meaningful information unbelievably fast. They were meeting outside on the fields, and inside by the fireside in the evening. They were telling stories. Old people were transferring knowledge to young ones, for example, where and when they could forage for mushrooms. They were not scholarly educated, but they were transferring all kinds of meaningful information, situated knowledge somehow. Where are we today with this sort of heritage? Connectivity has two important parts, access and meaning. We undoubtedly have the first part with the Internet and social networks, but do we have the second part? Social networks are great connectors between people, but are they communication-effective?

Most people develop online social relations with people whom they have face-to-face interactions with. In fact, new research shows that the online interactions support and enhance the physical relationship – helping to strengthen the bonds between people [6] [18]. However, when people do not know each other in the real life, interactions are mostly cognitive and cannot address embodied interaction that face-to-face communication provides. When the power goes out and all the batteries are dead, is there anything to remember? It takes more than beautiful pictures or movies to understand something. It takes a well-made head, in Montaigne's sense. This is a crucial domain where education must focus today.

Connectivity enables the creation of online-delivered education. The online format enables a democratic dissemination of knowledge around the globe. We now have the privilege of following a class at Harvard, MIT or Stanford. How do online and classroom instruction differ? Online learners can be self-paced, learning the instructional material at a rate that is appropriate to their ability. Online material can be reviewed as many times as needed. In many cases, the instructor is available for assistance and dialogue. This is an excellent style of learning for cognitive learners who prefer concrete, logical and sequential information! Further, online learning provides immediate feedback. Problems usually arise in the manner of evaluation. It is easy and profitable to use multiple choice questions (MCQs) exams using computer networks, and this is what is typically done, mostly by commodity. MCQs test knowledge but not understanding; this is where the problem lies. From this issue arises the most effective business model of online education. Currently, organizations that

produce online curriculum use almost exclusively the MCQs evaluation model. They generate money, but they are not engaging students in critical thinking, holistic thinking, or the process of building relational learning that develops long-term memory needed to solve problems or be entrepreneurial. They enable well-filled heads (when students do not forget what they have learned), but not necessarily well-made heads.

### THE COMPLEXITY ISSUE

There is a specific connectivity issue that also needs to be addressed, the connection between education and industry. For a long time, education and industry were disconnected, and they are still not well connected in many places of the world. Early American education was predicated upon the notion that school was a place to socialize groups of people to similar norms so that they could perform well in an organized or industrialized work environment. Education was not about enrichment of one's mental abilities.

Perhaps the term "industry" may no longer be appropriate as it generally implies production. As communication makes the world a more accessible place for all, it might make more sense to talk about and plan for the creation and management of technology. Production will soon become an exclusively technological process. For example, 3D printing will soon bring the manufacture of products to the home! The concept of schools is also evolving. People can learn at home, at a park, when they travel and in almost any location where they can be electronically connected. Soon people will connect virtually to places around the world via a Holodeck-like *immersive display experience*. Microsoft recently patented the first of such virtual life-like environments. Therefore, the notion of the classroom becomes almost obsolete. As already discussed, evaluation and practice remain major issues. School-as-factory is evolving toward a complex concept that is no longer reliant with timetables and locations. People already learn all of the time and everywhere; our brains are experiencing and learning at each moment. When we are interested in a topic, we learn extremely well because we are motivated. The education system that relies upon convenient timetables and locations goes against the brains natural learning process. An educational system not reliant on timetables and location will introduce complexity in terms of nodes and connections among these nodes, but at the level of people it could be very simple and highly effective. It is the total opposite of a simple systemic concept of the school-as-factory, which often leads to enormous challenges at the individual level, which we are currently experiencing as society changes and the education system fails to meet the needs of the new society.

The second half of the twentieth century was based on reductionist local linear engineering of complicated systems. Scientists and engineers learned to solve problems by reducing the world into pieces, often by linear approximations. Then they assembled these pieces to make

cars, airplanes and other complicated systems. This Cartesian approach led to very successful results. But today, the number of elements interacting in every system within our global and highly interconnected world has increased exponentially. It is more difficult to think locally because everything is interconnected. Biologists would say that separability is at stake, i.e., we cannot separate a specific part without breaking the whole. This is why we need to emphasize the entire world and its systems in a more holistic manner.

To understand the evolution of our socio-technical world holistically is to understand its complexity. This complexity is only going to grow. This is why we must consider teaching complexity science at school. We learned linear algebra at school because it was needed in the technology-centered engineering world of the twentieth century. Today, we now need to learn different concepts such as singularities, attractors, bifurcations and catastrophes in addition to those traditional concepts. Understanding dynamic non-linear and chaotic systems requires the acquisition of this knowledge. Underlying mathematics is very difficult and requires a solid theoretical background, but we can make it accessible to young people using information technology, such as visualization and 3D printing. We now have the means to make many abstractions more concrete, visually and/or physically meaningful.

Further, instead of dividing disciplines, we need to combine them through problem solving and action. No longer can we be *either* artist or engineer. We must be both. We must combine humanities and technology, even if specialized knowledge is still necessary. Complexity is our constituency. Biology is complex; environment is complex; we are complex! Life is wonderfully dynamic and is always in flux. We need to understand and appreciate complexity. Complexity is not the opposite of simplicity; the opposite of simple is complicated. We manage to do simple things in our complex world every day, because we adapt to this world. *Adaptation* is a crucial mechanism that everybody has, and needs to further develop. Success is not only a matter of individual adaptation, but also collective adaptation. Everybody brings his or her contribution. Youth bring the excitement, bold ideas and energy, while seasoned folks bring the experience and specialization. I had a few retiree students who contributed enormously to their younger peers.

Adaptation is crucial especially now in our constantly evolving socio-technical society. We operate within increasingly non-linear systems where emerge properties that we had never experienced before. We have, until now, been protected by linear procedures and simplified input/output parameters organized on a user interface. It is time now to examine and understand these new concepts and gain appropriate awareness of the kinds of emerging

properties that current systems are demonstrating and future systems are expected to demonstrate.

### **ORCHESTRATING AUTONOMY AND COMPETENCE**

If we expect that education will be more integrated into our digital society, it is also crucial that educators are given greater autonomy to manage the complexity of this growing socio-technical network. Agent autonomy requires more coordination and learning. Consequently, understanding relationships between autonomy, coordination and learning requires new organizational models. First, we should make a distinction between organizational learning (wherein organization learns) and learning organizations (wherein the organization teaches). I already advocated the fact that organizations are moving from the Military model to an *Orchestra*-like framework, i.e., from pyramidal structure to networked functions [1]. This shift transforms linear tree-like connections into non-linear network-like connections. It does not remove leadership. Networks need to be composed and orchestrated. Contributors, like musicians in the Orchestra framework, are more autonomous than twentieth-century workers, like soldiers in the Military model. But this autonomy requires new constraints such as competence, motivation and team spirit. Finally, autonomy also requires coordination at the composition stage and at the performance stage.

The Finnish school system<sup>2</sup> is an example of flexibility in coordination and performance. The system is based on centralized steering and local implementation. Education steering is managed through “legislation and norms, core curricula, government planning and information steering.” Towns are responsible for the provision of education and the implementation. Schools and teachers have large autonomy. They are highly qualified and committed. Being a teacher is very popular in Finland; the most motivated and talented university students are selected. Schools are highly connected with the socio-economical world. In addition, learning focuses on students' activity and interaction with teachers, other students and the learning environment. Learning environments are developed and work in a human-centered way. Consequently, it is not surprising that Finland scores among the best countries in education.

Since technology provides people with more autonomy, it is then important to develop more coordination among actors. This is precisely what the Finnish education system is about. It requires people and organizations that are able to “compose” norms and core curricula, like a composer would do for a symphony. It also requires people and organizations that “conduct” the implementation locally, like a conductor in a theater. People and organizations involved have to be competent in their roles, like musicians are in an orchestra. The Orchestra framework was already proven to be useful for analyzing socio-technical systems

such as aerospace systems, and more generally life-critical systems (LCSs) [3]. LCSs are typically characterized by three main attributes that are safety, efficiency and comfort. In this paper, we extend the use of this framework to educational systems. The Orchestra model will have to be extended, modified and adapted. More generally, models are good conceptual tools to better understand how the world works. Modeling goes with understanding and vice versa. This is why people should be familiarized with modeling from a very young age.

### **THE ISSUE OF CREATIVITY**

During the International Space University Space Studies Program held on the Florida Space Coast during the summer of 2012, we conducted a survey on “what Space can contribute to global STEM education” [2]. The responses clearly identified that creativity and innovation cannot be treated separately from STEM, and Arts should be an integrating part of a novel approach called STEAM. This study was conducted by 34 program participants and supported by ten lecturers coming from academia, government, research and industry, experts in Space and Education. Seventeen countries were represented. Three categories of countries emerged. In the least developed countries where economies start to evolve, mortality has to decrease and equality has to improve, STEM has yet to mature. In developing countries, STEM can be seen as a tool to drive economic growth. In developed countries, we observe a lack of interest in STEM education to the benefit of business disciplines. The findings of the study team determined that space contributions could nurture education because space sciences are about cognition, innovation and risk taking. These are three attributes and needs of our evolving societies. We are in a critical age where our civilizations are evolving faster than before, due to information technology integration in our lives. We then need to better understand where we are going and invent our future on Earth in the same way as we are exploring how we would be able to live on the Moon or Mars.

Based on previous unmanned and manned space programs experience such as Gemini and Mercury, the Apollo program showed us how we could deconstruct complexity, go to the Moon and come back safely. It was a very successful cross-disciplinary endeavor, one of a kind during the 20<sup>th</sup> century. It combined creativity and analysis. Apollo “composers, conductors and musicians” made “going to the Moon” a magnificent “symphony!” Creativity is about human needs, out of the box thinking, and breaking the standards; it is about purposes. Analysis is making these needs possible; it is about means. Today, we are almost always constrained by standards, evaluation, regulations and procedures. The precautionary principle seems to prevail. However, systematic procedures may lead to passive and sometimes absurd behavior. How will we be able to build new things then? I strongly believe that we cannot live well if we are not active contributors, if we are

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<sup>2</sup> <http://www.opf.fi/english/education>

not creating. It is fun to create! It is healthy to create! Creativity is a critical element in the nurturing of curiosity and our love of life. This is what young people need to learn and experience. Creativity should be the ‘c’ in communication, or talk will be only empty words. This is why motivation declines. Humans thrive to participate in life, in some way.

The current state of risk aversion (especially prevalent in many learning institutions) does not facilitate creativity. This is why it is urgent to think in terms of excellence, motivation, leadership, risk taking and learning by doing. Of course, evaluation is crucial, but it does not have to be performed as formal linear exams where students literally learn the day before and forget everything the day after! We need to do away with systematic exams only based on multiple-choice questions. Other types of evaluation, such as making things and trying them through peer reviews and tests, should also be used. A portfolio approach to evaluation can work and has worked in many disciplines over time; it is also scalable in many dimensions, linear and non linear. Research has developed that way, and it works. Why do not we do the entire education in a similar way? For example, we already have contests such as robot competitions where robot makers are mutually challenged, such as the NASA Lunabotics competition<sup>3</sup>.

## RECOMMENDATIONS

Learning thinking is definitively human-centered. We need to know who are current and future learners. We need to better understand how they are influenced by new technology, and what this technology can bring them. Learning thinking needs to be put into practice in our constantly evolving world, and experience must be accumulated and re-injected into education curricula.

Extending our capabilities through computer-networked devices is certainly great, but we need to be careful that understanding is the primary focus. In other words, such devices should be used using educated common sense and critical thinking. Connectivity is a reality today, and education does not have to worry about accessing information and knowledge any longer, it has to concentrate on meaning.

New advanced interaction media technology should be used to visualize and materialize (e.g., 3D printing) abstract concepts, and provide motivation to learn more about them. In addition, local linear approaches to engineering should be augmented and overseen by holistic non-linear approaches to design, (i.e., complexity science should be made accessible to anyone). Creativity and design thinking should be promoted at the same level as analysis and reasoning. “We must learn to be creative” [13].

The young generation should learn and train as contributors and no longer as lazy consumers of current technology. Technology should be considered as our slave and not a dominant driver of our lives. In addition to providing strong fundamental skills such as reading, writing and arithmetic, schools need to seriously address cross-disciplinary approaches and practices at a very young age, and all along undergraduate and graduate studies.

We need to better understand the term “digital native” when we talk about young people born with computerized devices in their hands! We also need to demonstrate “the effect of technology adoption on cognitive development, social values, and learning expectations”. Finally, we need to find out the “implications for educational policy and practice.” [9].

## CONCLUSION AND PERSPECTIVES

Human-centered design (HCD) is about cognitive engineering, life-critical systems, advanced interaction media, modeling and simulation, organization design and management, complexity analysis and assessment, creativity and design thinking, functional analysis, and user experience [1]. HCD not only provides us with tools and techniques to build useful and usable things, it also provides an integrated approach to learning by doing, exploring *possible futures*, and understanding complex systems. This is what *learning thinking* is about. Consequently, HCD is a very appropriate approach that would enable the re-design of education systems taking into account learning thinking.

More specifically, the HCD Orchestra framework is a thought-provoking metaphor that enables us to describe the possible evolution of organizations, and educational systems in particular. Of course, it will need to be tailored, modified and reshuffled to be really useful and usable for the design and development of future educational systems. In particular, the issue of orchestrating autonomy and competence requires more investigation. In addition, technology tremendously modifies our old ways of learning and teaching. People need to learn and master critical thinking because the Internet allows us to access “knowledge-by-proxy”. Knowledge is available but understanding is not guaranteed without specific training. Students can be more autonomous but they need to properly assess their consumption and understanding of concepts. They will need to identify the central questions or problems raised by what you’ve read on the Internet. They need to be able to answer a wide range of questions that would engage them in critical thinking. Who sponsored the publishing of the information and do respected institutions support the concepts? What are the core concepts you’ve learned and how can you articulate them? What will it require to put these concepts into practice? How might individuals in other circumstances interpret the concepts or put them into practice?

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<sup>3</sup>[http://www.nasa.gov/multimedia/podcasting/nasaedge/NE00072112\\_39\\_Lunabotics\\_2012.html](http://www.nasa.gov/multimedia/podcasting/nasaedge/NE00072112_39_Lunabotics_2012.html)

It is time to come back to long-term thinking. There are needs for building possible futures where sustainable energy must be further investigated together with the shift from the Military model to the Orchestra framework. We must cooperate and coordinate more, and new information technologies promise a great deal. Such goals will tremendously motivate young people whether at school or at home. Education can certainly be a great contributor to the evolution toward human-centered longer-term socio-technical possible futures, which should replace our current short-term financial predictions that inevitably lead to chaotic economies. Let's conclude with Alan Kay's 1971 famous quote, "the best way to predict the future is to invent it."

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