Training creative and collaborative knowledge-builders: a major challenge for 21st century education

"WHAT IS SPECIFIC TO HUMAN BEINGS IS THEIR GREAT ABILITY TO ADAPT"

Socrates

Disclaimer

This paper has been prepared as a background paper for the OECD Innovation Strategy. The views expressed herein are those of the author and do not necessarily reflect the official views of the OECD or of the governments of its member countries.

Mission

To draft a paper as a contribution to the OECD Innovation Strategy on the features of educational approaches and systems that appear to stimulate creativity, initiative, and risk-taking among students. The paper (about 40 pages) would examine selected theoretical contributions from natural and social science and compare selected features of educational approaches and systems across OECD countries. Based on this review, the paper would discuss the main implications for measurement and policy. Delivery date: 28 February 2009.

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Executive summary

In a world that is changing at an unprecedented pace, what can education provide that will prepare today's children for the challenges of the Twenty-first century? This report introduces the forces that lead to rapid environmental change and the impact of a relative lag in educational reform in chapter one. In the first part of chapter two, it reviews the strategies various species including our own use to adapt to the environment: exploration, exploitation, knowledge acquisition, cooperation, information transfer, and niche-tailoring. **Adaptibility and exploration are key** to any species that lives **in changing environments, where mechanisms generating innovations are being selected**. The biological metaphors described helps us to see why the importance of human creativity is growing as our environment change at an increasing pace thanks to the exponential development of science and information and communication technologies. However, education systems are evolving slower than the rest of society and traditional education is not optimally organised to promote creativity and the ability to update one's knowledge.

Hence, only the countries that implement policies to reform their education to promote adaptability and creativity in adults and children are likely to remain at the forefront of human development and technology. Lessons from the social sciences summarised at the end of chapter two, indicate that creativity, initiative, and risk-taking should be encouraged in **training today's children to become creative and cooperative knowledge-builders, *i.e.*, able to periodically update and productively use their knowledge** in their social and professional lives. Considering that student optimally develop these skills only in fostering environments, as well as the inherent difficulty in assessing creativity in millions of individual children, this report proposes focusing the creativity in education evaluation on the quality of the educational environment.

In chapter three, comparative analysis of education systems show that a huge diversity exists, interesting attempts are tried locally but only in some countries does one see national debates on the issue allowing the emergence of new education paradigms that can foster creativity. In terms of policy, chapter four proposes **experimenting with new educational schemes, developing creative**

environments and programs, and disseminating the best educational practices within countries and across linguistic barriers by organizing a network of well-designed experiments and information exchange that is accessible to all. Recommendations adressed to different stakeholders that want to promote creativity can be found below.

10 key recommendations to promote creativity in education

1) General recommendations

"You can't do it -- it has never been done." This sentence will stifle any creative effort from the outset. It is too often addressed to students, professors, or leaders who wish to promote change. In a future-oriented society, such a symbol of conservatism should no longer be an argument for deciding on the value of a project.

2) Recommendations for students

As students repeatedly said after opening-up their views on their own futures, "the biggest barriers were in my head -- self-censorship was my worst enemy." Once students dare to be creative and take initiative, they should work hard and sometimes fight conservatism, pursuing their ideas and finding what Ken Robinson call "their element."

3) Recommendations for parents

Build a nurturing environment in which your children can build their creativity and believe in their potential. Help them to find schools and universities where they can blossom and prepare for a future in which so many things will have changed.

4) Recommendations for teachers

Be available for students when they need your feedback on their ideas. Create courses in which they can develop their own projects. Network with colleagues who have similar views about pedagogy, regardless of their discipline.

5) Recommendations for schools and deans

Encourage the creativity in your teachers and students, and provide them the means in terms of time, administrative help, and space to develop creative programs in which students can work on individual and collective projects. If these programs cannot be open to all initially, selection to enter them should be based on students' motivation to take initiative and will to interact with creative students and teachers.

6) Recommendations for universities

Encourage interdisciplinary approaches and the creation of academic programs that can allow students to launch projects and to develop their creativity. Create "creative spaces" dedicated to the development of student projects open 24/7/365. These spaces should be organized as incubators for ideas and creative talents.

7) Recommendations for foundations

Foundations are the most flexible funding bodies, and often the most creative and reactive. As such, they can be the fastest to fund emerging creative programs and supporting them in the early stages, the same way venture capitalists support emerging start-ups. They could even go one step further and help create incubators that host such creative projects.

8) Recommendations for governments

Be sure your country is among the most attractive for creative talents. Foster a culture of creativity by organizing national debate on the subject. Sponsor publications and translations of books and TV programs dedicated to creativity. Create national programs to foster creativity in education. Organize national networks of interdisciplinary creative curricula and ensure their long-term funding.

9) Recommendations for OECD

Compare national cultures of creativity and programs designed to foster creativity, trying to correlate them with other indicators available in various countries. Promote international debate on the best ways to foster creativity.

10) Recommendations for creative communities of knowledge builders

Develop websites, open source tools, and places dedicated to promote storing, exchange, and creation of ideas among creative and cooperative knowledge-builders by facilitating both on-line and real-world meetings, ideally in creative places dedicated to such exchange. In order to maximize their impact, such websites should be available to all creative minds and be part of open education ressources[1].

[1] Their governance should be close to the one of wikipedia, yet they would focus on creative knowledge building through cooperative interactions.

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1. Why do educational approaches and systems that stimulate creativity, initiative, and risk-taking matter?

Endogenous growth theory reveals that education, research, and innovation are rate-limiting for economic development. In their book "Endogenous Growth Theory," Aghion and Howitt explain why nations should invest in education and research. Furthermore, investing in the development of creativity in education and in the work place can lead to further qualitative improvement, since those who work in creative knowledge are more able to face the challenges of a rapidly changing world. Whereas classical teaching leads to faster *dissemination* of knowledge in the workforce, teaching creativity speeds up the *accumulation* of knowledge, hence of innovation and economic growth.

The "Matthew effect," a phenomenon according to which "the rich get richer," also applies in academic settings, where it translates to "the more you know, the more you can learn." It is essential that all children be afforded an equal opportunity to become knowledge-builders, by acquiring the meta-skills that allow them to update their abilities and create new knowledge throughout their lives. A growing number of nations are trying to improve creativity, initiative, and risk-taking among their citizens. This report will discuss why such improvements are needed more than ever today, and why they can help us to devise policies that will bring about change in our education systems that will foster these qualities in the coming generations.

We live in a world that is changing at an unprecedented pace

The world is facing unprecedented simultaneous challenges today -- multi-faceted economic/financial, social, climatic, and environmental crises – for all of which we must find creative solutions. What is necessary on this large systemic world-scale is also needed at every level of our society that is undergoing change at such a pace. In fact, the rhythm of these changes appears to be accelerating. Obeying Moore's Law, according to which computing power doubles every year, information has been increasing at around 66% per year, much faster than the growth of any material goods.[2] In his book, "Science since Babylon," Derek de Solla Price shows that

[2] <http://people.ischool.berkeley.edu/%7Ehal/>.

scientific knowledge grew exponentially between 1700 and 1950, doubling every fifteen years. Today, in some fields like computer science, a fifteen-year doubling-time is considered very slow, since hardware and software become obsolete much sooner.

Innovation and creativity are becoming rate-limiting

In the knowledge economy created by these same revolutions, growth correlates with innovation potential. Companies therefore need the most creative people, those able to take initiatives, and nations want to have a workforce able to create value and jobs, while taking on the challenges of the day. Today, parents realize that their offspring are growing up in a very different world from the one they knew as children; that not only will their children hold jobs that are different from theirs, but will have to change jobs repeatedly. These factors show the need to encourage creativity and develop initiative in children.

Changes in education are not rapid enough

Yet, even as these changes occur, schools are among the places on our planet that would least surprise a 19th century time-traveler. Not that schools have not changed at all, but that they have changed less than other components of our societies, many of which have undergone exponential change. Despite some reforms, in too many places,[3] academic content and pedagogy have changed only minimally, often with regulations and a crammed curriculum, which hinder the ability of teachers to take initiatives. While classical education can sometimes teach how to work hard on well-defined problems, it is unlikely that this approach will develop initiative, risk-taking, and creativity -- or even the capacity to devise solutions to ill-defined problems.

The human-social-cultural environment in which children are now growing up is also changing. The new communications and travel technologies have led to mobility of information, ideas, and people. More and more cities and nations may now be considered multicultural or multi-ethnic, as a result of the arrival and cohabitation of people of a wide variety of origins. Education in such multicultural places can be an asset, if every child is well integrated, as is the case in some international schools.

[3] Just to give an example: in France, the elite "*classe préparatoire*" program includes very little physics that is posterior to 1905, and the way these courses are taught has evolved only minimally in decades.

However, integration is not always successful, due to the lack of appropriate resources, to the misconceptions of some individuals and the fears that derive from them. This is of great consequence for the political and social institutions, which must urgently adapt to the new situation. Educational structures often have difficulty dealing with students of foreign origins. The integration and participation of these students in society is at risk here. Schools should focus more on developing abilities that will really be needed in future life, using methods that acknowledge the legitimacy and value of everyone's participation. Fostering creativity, innovation, and risk-taking could be a first step toward that goal.

Ignoring the changes in the world cannot be the solution

Whereas the environment is becoming less predictable, formal education still too often prepares students for a static world. Whereas students will have to collaborate in interactive and interdisciplinary teams, they are still too often trained in a competitive mode that divides the acquisition of knowledge into disciplines. Whereas we need students to develop their abilities to critically analyze the flow of information they receive, in too many places they are still not encouraged to question teachers' knowledge. Whereas today's children take dangerous risks, it would be better for them to develop a more positive risk-taking attitude, such as taking chances on engaging in challenging activities that allow them to develop their creativity[4]. Whereas we should educate children to be more adaptable, more able to take advantage of opportunities proposed by the new technologies that characterize the digital age, often their main access to modern technology is outside the classroom.

Some people fear these technologies, believing that forbidding the use of *Wikipedia* will protect the new generation from imaginary future threats. Socrates appear to have been suspicious of writing, which he considered an innovation that would allow the brain to become lazy by leading readers to believe they "knew" something merely by possessing it in written words. During the Renaissance, some people believed

[4] In "Understanding Youth, Adolescent Development for Educators," Nakkula and Toshalis describe how teenagers need to take risks in order to construct themselves. If we encourage them to build their personalities by developing positive risk-taking attitudes that allow them to explore at the limits of their comfort zone, where they feel challenged and motivated and able to progress, they will not only learn faster and be more creative, but may also avoid some of the dangers associated with life-threatening, risky behaviors.

that printing books would lead to the degeneracy of the writing culture. Clearly, writing and printing have to a large extent changed the world of knowledge – and not necessarily always for the worse! Although writing, printing, and the Internet have changed the world, we also must adapt to such changes by learning how to master the tools of communication and socialization -- instead of remaining ignorant of them, fearing them, or rejecting them.

After the family home, school is where children are socialized. School is therefore of great importance in children's lives, since it influences and determines their future roles as citizens of the world, their contributions as members of a social community. Childhood and adolescence are often seen as periods of unawareness. As adults, we face many responsibilities -- professional, financial, family – which makes us less willing to be creative or innovative -- or to take risks. Childhood may not be as peaceful a period as adults like to imagine, and it is certainly a period of discovery, initial experience, and mistake-making, during which children learn how to interact with their immediate surroundings and begin to recognize the challenges humanity faces. Schools are among the most important places for children to encounter these challenges, where they create social bonds with those from different backgrounds. But when we consider the increase in the number of home-schooled children, "spatial segregation," and other separatist phenomena now widespread in many parts, one wonder how long schools will continue to play that role. Most of all, abandoning schools would deprive children the opportunity to confront a reality different from the one that they knew while constructing themselves. By meeting students and teachers from other social, cultural, ethnic, and economic backgrounds, children experience the diversity of the world and learn to work in groups; to share and discuss, where they defend -- and sometimes withdraw or improve -- their ideas.

What should children of today learn?

Obviously, education systems are very diverse, and opinions concerning them are even more scattered. By default, many parents want their children to be educated the same way they were. This is perfectly understandable, since it facilitates communication between the generations; it is easier if generations use the same codes, play the same games, sing the same songs, spell the same way. However, while this works fine in a static world in which children grow up in an environment that

does not vary much from one generation to the next, it doesn't work in a world that is undergoing change at an accelerating rate. Children today may not know the names of all the mountains and rivers in their country by rote, but they can find them -- and much more -- by using *Google Earth* to hover and surf over the reality of these mountains and rivers. But because such an approach to knowledge is so rarely taught in schools, we are beginning to see the gap among children of different backgrounds widen. We are surprised to learn that children love technology, even as they increasingly desert scientific education, which they consider to not be stimulating. When given the chance, they seem however eager to investigate the unknown, but this is only possible so late in their studies that most opt for easier choices. Rather than addressing these issues openly and directly, education systems still too often use 19th century tools, adapting too slowly to the best practices and new tools[5] available today, to often ignoring the achievements of pioneering schools[6] and research on cognitive and education sciences,[7] thus not developping skills that would be needed in a future in which the only thing that is sure is continuous change.

As the ancient Chinese already knew, "the only thing that doesn't change is change itself." We will therefore argue that learning to learn -- learning how to synthesize information, to test knowledge, to collaborate, to criticize, to accept criticism, to communicate ideas clearly using all the tools of the day, to take initiatives, to dare to take risks, and how to be creative -- should all be part of any curriculum. Whereas the latter three items are the main focus of this paper, we will argue in favor of a systemic view, in which all the above meta-competencies must be developed, since one cannot be truly creative without mastering all the other skills listed above. Education cannot encompass the exponential increase in knowledge. Along with Edward Wilson, in his book, *Consilience*, Marlene Scardamalia and Carl Bereiter[8] argue that if one understands something deeply enough, its essential principles

[5] For a review of the tools available today, one can refer to the recent book by Andrew Zucker, "Transforming Schools with Technology: How Smart Use of Digital Tools Helps Achieve Six Key Educational Goals."

[6] For a review of how success can be achieved even under unfavorable conditions, see Karin Chenoveth's book, It is Being Done: Academic Success in Unexpected schools."

[7] For an extensive review of this literature, see for instance, *"How people learn: brain - mind experience and school,"* edited by the National Research Council.

[8] http://ikit.org/fulltext/AnnBrownOct10.06.pdf

emerge and meta-competence will be acquired. So, In the age of the Internet and search engines, we should stop quarrelling about the exact content of what we teach children, but be sure they master these meta-processes, which are essential to any citizen of the 21st century in order to work at a stimulating job and enjoy a fulfilling life.

2. What have we learned so far?

2.1: "How can one adapt to changing environments?"

As stated in the introduction, education should allow children to adapt to an environment that is changing faster and faster. The next generation will live in unprecedented times, different from what has been experienced by any previous human generation. The mission assigned this author by the OECD was to review *"selected theoretical contributions from natural and social science and to compare selected features of educational approaches and systems across OECD countries."* Indeed, to gain insight into the consequences of today's rapid flow of information, it may be useful to examine theoretical contributions from the natural sciences concerning various modes of knowledge acquisition, innovation, and adaptation to the environment. Prior to describing what we have learned from the social sciences and from pedagogical innovation, we will thus summarize these contributions for the reader in a box. The reader may wish to move directly to more human perspectives, but understanding others species' abilities to adapt to changing environments may yield worthwhile metaphors and analogies that improve our intuition concerning the challenges we are facing, as other organims have had to adapt to environments that change at accelerated speed.

Box: Adaptability in biological systems

Since Darwin, since have known that biological organisms adapt by natural selection. We will argue here that if the views of evolutionists have sometimes had bad press in the humanities, it is either because these perspectives were not well understood or were wrongly associated with extremist ideologies. We will present

the most relevant refinements of evolutionary theory, arguing that in today's society, the time scale are not those of thousands of generations but of years, hence selection applies not to *humans*, but to ideas and their modes of transfer. Our understanding has been greatly refined, but it is to Darwin and Wallace that we owe our understanding of the interplay among variation, selection, and amplification; that they are the key to evolution[9]. If these processes are iterated over many generations in a constant environment, the yield is even more well-adapted genomes.

The Red Queen environment

We now know many other things about biological evolution, but the basic principles of survival of the fittest are key to classical evolutionary biology. We also know that a variety of factors may be responsible when a genome is not perfectly adapted to an environment. In a small population, the random, ”luckiest” ones survive. In a real environment, in which organisms interact with one another, interesting dynamics may prevail, since fitness depends on the presence of other individuals.[10] Environments such as the arms race have been called “Red Queen environments,” in tribute to Lewis Carroll’s "Though The Looking Glass" character, who keeps running with Alice without moving. It is interesting to note that Lewis Carroll lived at the same time as Charles Darwin and Alfred Russel Wallace, in a society that had already undergone many changes. In the fast-changing Victorian society that had experienced much innovation since the beginning of the industrial revolution, it was clear, as the Red Queen said, *"…it takes all the running you can do, to stay in the same place."* This famous remark conveys the idea that in a world in which everybody else is running, you must to constantly adapt in order to remain alive.

[9][10] Individual variation exists among a population of organisms that colonizes a new environment. However, not all such differences matter; some are not associated with genetic variation, while others allow certain individuals to reproduce in greater number. Some of the latter variations are transmitted to the succeeding generation, an average of whose individuals are more well-adapted to the environment. New variations, yielding new diversity, are introduced by random Generators of Diversity (GoD), responsible for the mutation and recombination of genetic material during reproduction. In a constant environment, the result is ever more well-adapted genomes.

[10] For instance, in a predator-prey relationship, if the prey runs faster, slower predators will be out-competed. In host-parasite interactions, if the parasite happens to have a mutation that allows it to escape the defenses of the host, there will be a strong selection on the host immune system to find a counter-measure.

The handicap principle

Another part of the puzzle for Charles Darwin was the peacock's tail. Why should peacocks have such a beautiful but cumbersome feature? The answer, proposed by Zahavi, was coined the "handicap principle." Clearly, such a tail must be a handicap, for instance, in avoiding or escaping predators. But peahens prefer peacocks with the biggest tails! The handicap principle argues that for females, selecting males able to survive *despite* such a handicap is a way to verify that a male is fit; that they have good genes. Once peahens developed a preference for peacocks with longer and more elaborate tails, a runaway selection process was established, and the Red Queen logic applied thereafter, based on the principle of tail beauty. The handicap principle has been proposed to explain many traits that are costly but that may be favored by selection, since they serve as a trustworthy indication of quality. It may even be argued that altruism, for which it is hard to select because it is costly to the individual, could in fact be selected via this very logic in species possessing sufficient cognitive abilities to create reputation systems. In such species, an altruistic act would increase mating probability, hence conferring a direct advantage. In species that are able to reciprocate, altruism can also be indirectly favored, since the favor is more likely to be returned. More generally, it is possible to select for cooperation if cooperators are more likely to interact with one another than with defectors. This could be explained by reputation systems, or because kin are more likely to interact together. Therefore, a selective pressure exists for the ability to recognize cooperators. However, cheaters have a lot to gain if they can subvert such systems; so a Red Queen process may also operate at this level[11].

When the pace of change changes

Interestingly, in the Lewis Carroll text, the Red Queen's next sentence is, *"if you want to get somewhere else, you must run at least twice as fast as that."* This suggests that if you want to invade a new niche or be the first one in a new market, it is not enough to run; you have to produce novelty at a faster rate than the others. One should remember that in well-adapted biological systems, most variants can be only detrimental; thus, increased mutation rate is a form of genetic risk-taking. Therefore, in a constant environment, once adaptation has occurred, natural

[11] This may explain the fast evolution of language dialects and codes among humans.

selection will minimize the mutation rate. However, in variable environments, it is clear that there is not only pressure to adapt, but also pressure on the *speed* of adaptation[12]. Although bacteria do not possess cognitive ability comparable to that of brained animals, some people, including Henry Plotkin, argue that bacteria use Darwinian heuristics to acquire knowledge about the environment. It may be said from this point of view that not only do bacteria acquire knowledge about how to resist antibiotics, they also *learn how to learn,* in the sense that having increased their mutation rate, they will thereafter be more likely to acquire new genetic knowledge[13].

Learning to adapt

Plotkin postulates the existence of three other Darwinian heuristics for acquiring knowledge. Like the one described above, these all include variation, selection,

[12] While it is difficult to prove something like this in a controlled way in many species, it is possible to produce experimental evolution in bacteria, in which all the parameters can be measured and the corresponding data used in computer simulations to test the logic announced by the Red Queen. *In vitro*, *in silico,* and *in vivo* work have converged to show that when facing strong challenges, such as repeated antibiotherapy, surviving bacteria not only carry the mutations that allowed them to survive the antibiotics. Such "lucky" survivors have increased their mutation rate and thus their likelihood of finding solutions to challenges that they may face in the future. This is not due to any "divine" intervention, but to the fact that, to paraphrase Louis Pasteur's famous dictum, "*chance favors the prepared mind.*" Here, chance "favors the prepared genome" *i.e.,* the one that by chance has a different mode of yielding variation, for instance, by having a mutation that disables an error-correcting gene.

[13]

If adaptation to antibiotics is clearly due to natural, or first-order selection, the ability to select for a broader Generator of Diversity (alias GoD), sometimes called second-order selection, is common among bacteria. In fact, it is possible to demonstrate theoretically and experimentally that there may sometimes be competition and sometimes synergy between mechanisms that increase genetic variability. In other words, natural selection selects not only successful genetic variants, but also the mechanisms that generated those variants. For instance, if the environment repeatedly switches between two conditions, one that selects for the activity of a gene and one that counter-selects for it, such second-order selection will select for a mutational hotspot, a mechanism that allows focusing diversity generation on a site under selection for variation. In more unpredictable and stressful environments, second-order selection may select for the induction of the expression of error-prone enzymes under conditions of stress, thereby increasing the mutation rate, thus the adaptability during periods of stress.

and retention or amplification. In evolutionary terms, the one that next appeared resulted from trial-and-error learning by animals with a brain. Interestingly, in the "Runaway Brain," Christopher Wills maintains that the Red Queen arms race also applies to brain size, selecting for ever-larger brains among competing animals. The same way predator/prey interactions can select for increased speed in both runners, brain size can select for wiser animals, since the brightest individuals may be more likely to have offsprings. Read and Lefevre[14] have also shown that the biggest-brained birds and primates are more likely to innovate than other species. The idea may therefore be advanced that the ability to innovate and diversify behavior and food sources was probably key to the adaptation of these animals. [15]

Selection for exploration, play, boredom and lazyness

Many foraging animals must choose whether to explore the environment looking for food or to exploit what they have found which may see its value decline as they exploit it. Given a limited time budget, should one explore or exploit ? If the environment is changing fast and the quality of the resource is decaying fast, one can see that one may have to spend an increasing amount of time exploring.

Another interesting comportment that has emerged in big-brained species is playful behavior among the young. Such behavior refines their skills in a secure setting, in which risk-taking is minimized and errors do not have dire consequences. The ability to spend leisure time playing seems to have been selected under various circumstances, when complex understanding of physical and social interactions could be safely learned. Underestimating the importance of human children playful and exploratory behavior may hence be a mistake that minimize their future adaptation.

Interestingly, when Sony researchers wanted to develop a playful explorative behavior in Aibo, their robot puppy, they had to code for "boredom," in order to observe truly explorative behavior. While they were programming the robot dog to

[14] (http://content.karger.com/ProdukteDB/produkte.asp?doi=10.1159/000076784)

[15] Innovation in animals was reviewed in their "Animal Innovation" book by Read and Laland, in which they cite a young female macaque that achieved two successive major innovations that enabled her to eliminate sand, first from potatoes, then from rice (to get some idea of macaque creativity, try to think of a way to eat rice mixed with beach sand without using tools.)

continue exploring as long as it was learning, the robot was stuck in a pattern of continually repeating very similar behavior, as if there were always something new to be learned, even if the learning steps became smaller and smaller. When they programmed the robot to change its behavior when the learning curve showed a diminishing return, the robot began to explore the whole environment. Boredom can be seen here as emerging from learning that is not as useful and challenging as it could be. In this light, we may be able to better understand why so many students feel bored during their studies.

In ants, as many as 78% of the inhabitants of a colony seem to remain inactive[16]. This proportion is quite robust (manipulation that modifies the initial state, separating active and inactive ants for instance, leads to a return to the initial activity distribution). One wonders why this "laziness" has evolved in such species that are often considered to be among the hardest-working. Entomologists have proposed that this free time is an asset that is selected for to increase adaptability and resilience while allowing for physiological needs. Here again it maybe that filling up too much human children schedule may end-up being counter-productive, as described below, allowing time is key to creativity.

Evolution of information transfer

The ability to transfer information between brains emerged in some animals, since observing the behavior of others facilitates learning. For this third Darwinian heuristics, Plotkin again argues that to be imitated, one must remain alive; that as a result, on average, more successful strategies are more likely to be copied. Social species therefore have had an extra advantage, since adaptive behaviors can be spread by social learning, which may have resulted from blind imitation of the most prevalent behavior[17], before it became possible in some species to evaluate the consequences of such behaviors.

In a limited number of species, teaching, defined as a costly modification of behavior from one individual to facilitate the learning of an adaptive behavior by

[16] Hölldobler B. & Wilson E. O. (1990) The Ants. Springer Verlag, Berlin.

[17] To illustrate this point, the young female macaque described in the above note was progressively imitated by others. Interestingly, the first to do so were her young friends; the adults learned only later, and the dominant males were the last ones to adapt this innovation.

another, has been reported. In such species, individuals do not learn merely by observing another individual execute the behavior for its own good, but because the "teacher" actively transfers some of its knowledge to the “learner.” Such active transfer of information, in which the teacher modifies its behavior to maximize learning, is found even in social insects. It is even more spectacular in meerkats, a species of small African mammal in which the mothers have been seen to carry live scorpions in their mouths to show their young how to hunt one of the few abundant sources of food in the Kalahari desert.

Some birds go a step further, in the sense that they not only transfer information to their kin, but also to other individuals. In the case of the honeyguide bird, this goes even one step further, since members of other species are the intended recipients of such information[18]. This interesting example is a case of a symbiosis in which providing information to a partner of a different species results in being converted into an energy-rich reward.

Adapting the environment instead of adapting to the environment

Before we discuss the impact of the ways humans have mastered new information technologies that enhance their ability to adapt to the world, let us describe other strategies that can maximize the fit between a genotype and an environment. If the fit is non-optimal, it may be because the organism encounters better conditions by migrating. This strategy, known as niche selection, is widely observed both in nature and human societies. Still another way to maximize the reproductive success of an organism that is not adapted to its current environment is known as niche tailoring or niche construction[19].

[18] Honeyguide birds (*Prodotiscus* sp.) sing a specific song when they encounter a honey badger (ratel) -- or a human! The mammal is attracted to and follows the bird, which leads it to a bee nest. The badger or human plunders the nest for honey, leaving the beeswax and larvae for the bird.

[19] A beaver living in a stream has greater difficulty escaping its predators than one living in a lake. Constructing a dam allows it to improve its environment; to construct its niche. Later, its offspring are likely to inherit the tailored niche. Note that this is not always the case; for instance, competitors could also benefit from the construction of such a niche, leading to a well-known problem, known as *the tragedy of the commons*, since the beaver that contributed to the public good may not be the one that benefits from it. For instance, some ants are known to specialize in raiding other species’ nests and installing their queen in a "palace" built by others. Furthermore, niche construction

Transferring information in order to cooperate

Interestingly, information transfer and niche tailoring seem able to co-evolve and lead to more elaborate strategies. For instance, when bacteria colonize certain environments, they may have to produce "public goods."[20] The problem they face is size; since they are only one-millionth of a meter in diameter, it is very expensive for them to efficiently carry out such behavior individually. Ideally, they would do it only when surrounded by numerous relatives. But since they can't see, how do they know whether they are sufficiently numerous? The answer is that bacteria utilize *quorum sensing*, [21] a mechanism they use to count themselves and to "decide" whether to invest in niche construction. Co-evolution of information transfer and niche construction can even go a step further, as exemplified by the fact that bacteria not only share information about their numbers, but also exchange information that allows them to carry out the elaborate activities required for niche construction[22].

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can also indirectly affect other organisms living in the same environment: by building a barrage, thus creating a pond, the beaver also unintentionally modifies the entire ecosystem for many other species, in which case we sometimes speak of *ecosystems engineering*. This term underscores the implications of such behavior, but, of course, does not imply that beaver behavior is selected to affect anyone else's reproduction.

[20] Such as molecules that detoxify the environment (*e.g.*, destroy antibiotics or detoxify pollutants) or that allow them to build rafts at the air liquid interface.

[21] All bacteria secrete a quorum-sensing molecule; if its concentration is low, they are not numerous enough; if it is high, there may be many relatives around.

[22] Unfortunately for us, such elaborate strategies can even defeat human medical advances. In the arms race between human pharmaceutical tools and bacteria, we had the upper hand in the 1940s, when we introduced antibiotics. Since we had several of them in our arsenal, we thought we would be safe. Today however, because some pathogenic bacteria contain mobile elements known as plasmids bearing genes for multiple antibiotic resistance, they are invulnerable to all antibiotics. These plasmids have collected genetic information from various species. During this process, the Generator of Diversity (GoD) mechanisms that have assembled this counter-arsenal have evolved. The evolution of tools that use refined modes of information exchange to increase the adaptability of bacteria are unforeseen consequences of our use of antibiotics on *plasmids*, which can be very efficiently transferred not only within a species, but across species. Plasmids carry a variety of other genetically coded traits. Sometimes they act as parasites, harming their host, and sometimes as symbionts, conferring a selective advantage. They are very often associated with the production of public goods. The transfer of these autocatalytic elements can also contribute to distribution of the ability to modify the niche among different species, which then collaborate symbiotically, degrading antibiotics

In the above box, entitled "adaptability in biological systems", we have seen different strategies used in nature by organisms that could not have survived without them especially in environments that change fast because the other organisms that shape selective pressures are themselves evolving. These strategies include the ability to explore and exploit, to learn, to forget, to learn how to learn, to signal one's quality, to transfer information, to teach and to cooperate. When the organisms are not adapted to a given environment, they can also migrate, or modify the environment rather than adapting to it, often via collective action that can extend among non relatives and sometimes among species. Even behavior like play, exploration, boredom and lazyness are believed to be adaptative as they can increase adaptability and resilience. Finding such behaviors in nature can only serve as a metaphor for human societies, but it may help us shed new lights on the future of education and on the dynamics of our evolution. As we'll see, like genetic evolution, human creativity requires generation of diversity and selection followed by amplification of the succesful innovations in an appropriate environment to be able to have a large impact. In both case, one should allow for exploration before exploitation can be possible. Humans have been able to modify their environment at a pace that keeps accelerating thus one cannot always exploit the same solution as it is likely to become obsolete. Creativity and exploration are thus more needed than ever as our technologies allow always faster transfer of information and accumulation of scientific and technological knowledge. Clearly *homo sapiens* have developped many more efficient ways of transferring information than any other species and in the next section we'll discuss the coevolution of human knowledge and of our ability to communicate.

Co-evolution of human knowledge and the ability to communicate

Language, writing, and printing as the first communications revolutions

Humans have also discovered new ways to transfer information that enormously

that could have killed them all. In addition, plasmids threaten future pharmaceutical progress, because it is likely that a new antibiotic challenge imposed on bacteria will be met faster than it would have been sixty years ago, since bacteria have refined their adaptive tools in the meantime.

sped up their adaptive abilities. Language has allowed us to verbally transfer virtually unlimited quantities of information, and grammar has made it possible to combine ever more complex groups of words into meaningful and precise sentences. But spoken language, the wonderful tool of the first human communications revolution, has a limitation: it can only be used to transfer information during the here and now, and only to those who are present. Building on the previous generation of language technology, the advent of writing expanded information transfer in both time and space, constituting the second human communications revolution. The inscription of words on durable material made possible by writing provided those who could read access to information without having to be in the physical presence of the producer of the information. The third revolution, printing, again built on the one that preceded it. Printing made possible the simultaneous production of many copies of books, enormously reducing their cost and leading to an explosion in book production, as well as increasing the number of literate people, who could then exchange information from all realms of human life. Elisabeth Eisenstein described in details the importance of the printing revolution in early modern Europe, and its consequences on the Renaissance, the Reform and, more importantly for the rest of this report, the emergence of modern science.

Science as a new mode of producing knowledge

For Henry Plotkin, after genetic evolution, individual learning, and social learning, science is the fourth Darwinian heuristic able to produce knowledge. In science, it is clear that there are selective processes that allow the spread of the best ideas. But it may be a surprise to find science described as a process of random variation. Some authors, such as Campbell, Plotkin, and Simonton, argue that scientists are not always good judges of the future success of scientific papers, and that scientific creativity may emerge from random interactions among different ideas. Furthermore, no single neuron knows what a good theory is, and since molecules in all neurons are subjected to random events, it is likely that some randomness occurs, which is succeeded by a variety of selection steps, first in the scientist's brain, then when the idea is tested by experimentation in the scientist's own laboratory, in colleagues' laboratories, and, if the idea is successfully developed and adopted, in technical applications. Whereas Plotkin draws a parallel between science and the previous Darwinian knowledge production heuristics, he also clearly spells out the specific

power of science. While previous forms of knowledge were based on the selection of what had worked locally in the past, science is more powerful, since it infers laws from past local observations that can very accurately predict and plan future unprecedented events in different environments, such as the ability to launch a man to the moon.

Printing and the emergence of modern science

Drawing on the historical analysis of Eisenstein, it may be claimed that science was an unforeseen consequence of printing, since printing enabled the increase in information flow that allowed many brains to connect and collaborate in order to produce knowledge and to define new means for producing knowledge. It also changed education and the conditions necessary for the emergence and spread of creative ideas. To better understand the way modern education and knowledge-building can be affected by new modes of information transfer such as the Internet, it may be useful to briefly summarize some key turning points, which were quite revolutionary at the time and that still have an impact on today's world.

For instance, Elisabeth Einsenstein describes how Copernicus could access the many astronomical observations recorded by authors of the past, which were available to him in various books. He was then able to propose a new theory, which could in turn be published and further refined by others. Born in 1546, the young Tycho Brahe was probably not the first child fascinated by stars, but was just fifteen when he escaped his mentor’s surveillance to consult books thought inappropriate for him, including Copernicus's. The young autodidact produced major innovations, eventually creating one of the first modern research laboratories. To examine astronomical theories, he wanted to observe the “Book of Nature” and developed the first astronomical institute, where as many as thirty people worked, constantly accumulating data, using the printing press Tycho installed to disseminate it. His observations would be followed by the analyses of his assistant, Johannes Kepler, which led to Newton’s understanding, in turn playing a key role in extending our ability to express the laws of nature in the language of mathematics allowing others to develop future technological and scientific progresses.

The exponential increase in scientific knowledge

By the beginning of the 18th century, scientific institutions were being funded,

scientific journals had begun to appear, their numbers growing exponentially -- doubling every fifteen years -- as described by Derek de Solla Price in the 1950s. The simplest way to think of such a rapid increase in scientific knowledge, which grew a million-fold in three hundred years, is to realize that future progress at any point in time is limited by the quantity of knowledge produced in the past.

During the 19th century, entire disciplines were constructed, with specific curricula defined so as to maximize the selection of talent and to exploit the results produced. Specifically designed laboratories were built in ways not so surprising for this period of standardization, which was associated with the industrial revolution. By then, it had become impossible to fathom the whole of knowledge, and a process of specialization and standardization in education had taken place.

This led to even more progress, since each discipline was in competition with others in attracting the best young brains to participate in the expansion of knowledge and the development of useful tools. The 20th century saw the advance of mathematical, physical, and chemical sciences transformed into progress in biology and computing. Progress in biological science allowed us to decipher the information contained in the genetic code[23], and computer science led to the emergence of the digital age. Computers enabled us to increase our storage capacity immensely, well beyond what books could do. Massive increases in the power of computers also made it possible to continue refining our mathematical understanding of the world.

The impact of the digital age on science and education

Computers have led to a very rapid redefinition of many jobs. One of the most symbolic moments was when the IBM computer *Deep Blue* won a chess tournament with Garry Kasparov, then world champion. *The Economist* commented, "if your job looks like chess, be ready to change jobs".

Science itself was affected a few years later, when *Nature* published a paper entitled, "The Robot Scientist." In that paper, a robot is described as achieving a complex series of steps that involved planning, experimentation, and analysis, by iteration. The robot's analysis of the first experiments led to the planning of what the next ones should be, in a manner revealed to be more efficient than what any human could

[23] As for Moore's Law in computer science, the rate of increase in the number of DNA sequences available in databases is also growing exponentially, while the price is falling.

attain. The implications of the fact that computers can be more efficient than humans not only in calculation (which had been achieved decades earlier), but also in such activities as chess and scientific research, considered by many to be among the most refined human activities, are far-ranging.

Since the present report is concerned with education, we will return to discuss these implications for the students of today and tomorrow. Suffice it to say now that education systems that permit new generations to take advantage of such progress are likely to fare better than those that ignore it, since many jobs will be affected by equivalent progress in the abilities of computers and robots.

Obviously, scientific and technological progress continues to increase at an ever-faster pace. Today, the Internet makes connections possible among computers, resulting in yet another technological revolution in information transfer. Whereas the first generation of Internet website stored information available to users, most often in *one-to-many mode*, e-mail permitted *one-to-one* interaction, and web 2.0 tools allow non-specialists to interact with each other on the web, thereby creating new social interactions and redefining old ones. With the decreasing price of microchips, and their installation in many machines and mobile devices, technology is going one step further, progressively allowing machine-to-machine interaction. Tomorrow's machines will increasingly include sensors that detect changes in the environment that can be linked to robotized machines, which in turn act on the environment based on information, which can then be processed by a third machine -- all this without direct human intervention. This will further facilitate the progress of science, which may then (for instance) be better able to understand climate change by using a network of automated sensors, eventually helping us to adapt more quickly to environmental changes we trigger.

It is hard to tell what the future of our children will be like with such rapid changes. In his review entitled, "The information age and the printing press, looking backward to see forward," James Dewar suggests that the influence of the Internet will be as important as that of the printing press, which changed the world between the renaissance to the enlightenment -- and beyond -- to the industrial revolution. Both the printing press and the Internet sped up the flow of information, to which all of society adjusted, radically changing education, science, and information access. To

cite just one example, the encyclopedia project, could never have been achieved without the printing press, which had also made it possible for an enlarged readership of a given book to write to its editors and authors, contributing to the collective improvement of knowledge. Obviously, the increased speed of information flow has led to an exponential increase in Wikipedia articles, at a pace Diderot and d'Alembert could not even dream of in the "salons" of the 18th century. Such places, where people discussed ideas they had read about, may be considered the precursors of modern creative places (additional discussion below.)

2.2 Creativity and education

After this description of how natural and human systems adapt to a rapidly changing environment while contributing changes in the environment, we will sum up the important lessons that may be drawn from research on creativity and education, as seen from the perspective of the social sciences.

Cultures of creativity

Simonton and others have investigated the differing rates of apparent creativity in various societies and periods. The principal conclusion of social science is that while no culture is completely closed to innovation, conditions that favor innovation are more likely in some of them. Hence, it is only by concealing the cultural and social features of the impact of change on a society that innovative policies fail to attain their goals. Creativity, innovation, and risk-taking are therefore inherent capacities of human beings and societies that must be encouraged on both the individual and collective levels in order to become effective.

Transformations do occur in all societies, and in a variety of domains -- education, religion, family, law -- yet sometimes it is difficult to study them well if all the component influences that bear on their outcome are not taken into account. The evolution of anthropology is representative of the difficulties researchers encounter in perceiving and reflecting on changes and transformations that constantly occur in human societies. While seeking universal features of human cultures, anthropologists have tended to emphasize the stability rather than the dynamics of cultures. The deep-rooted and long-lasting opposition between traditional and modern societies that is used to distingish Western societies from others is based on the belief that some cultures remained “pure,” and did not undergo evolution. Despite some

rectification, this distinction proved inadequate to accurately represent the complexity of human cultures. The shift occurred when researchers refused to associate themselves with given schools of thought or ideology, preferring to base their analyses on facts and direct observations. In France, two anthropologists, Roger Bastide and Georges Balandier, who introduced the field of "dynamic anthropology," led this evolution. Their work focused on cultural and social transformations resulting from interactions among human groups in every part of the world. The anthropological notion of "acculturation" was introduced to describe this phenomenon and the process of selection, adaptation, destruction, and recreation that accompanies it. We may conclude that every society is confronted by changes to which it is able to adapt.

The analysis must be completed by recent findings in the field of the anthropology of development. Derived from the distinction made between traditional and modern societies, or between developed and developing countries, this narrow field has yielded very interesting data on social and cultural reactions to radical change. Despite the introduction of technological innovations, colonization is known to have had deleterious effects in most of the populations who endured it. Even now, certain development programs fail because they do not respond to local needs, resources, and abilities. For this reason, those with a good knowledge of local customs are increasingly solicited to undertake projects that correspond to the prevailing local situation. The complex and limited transferability of models and solutions should not prevent the development of cultural exchange, but rather reveal the importance of equalitarian and voluntary collaboration.

The authors of "Applying Ethnography in Educational Change"[24], point to the historical role of communities in initiating and advocating educational change. It is only with their support, advice, and collaboration that effective policies may be developed. This is particularly true for programs and measures aimed at fostering creativity, risk-taking, and innovation, since development of these abilities among students requires profound personal implication. To be creative, innovative, and ready to take risks, students need to feel it is worth the effort.

[24] Jean J. Schensul, Maria Gonzalez Borrero, Roberto Garcia (Source: Anthropology & Education Quarterly, Vol. 16, No. 2, Applying Educational Anthropology (Summer, 1985), pp. 149-164, published by Blackwell, on behalf of the American Anthropological Association Stable URL: http://www.jstor.org/stable/3216363

By recognizing the validity, legitimacy, and rich potential of diverse forms of teaching and learning, school can play a major role in the social integration of children. In terms of education, the example of the international school is the best indication of the value of cross-cultural education in building bridges among people of different cultural and social backgrounds. Confronted with other traditions and practices, in terms of education but also of the arts, lifestyle, and food, both students and teachers develop a more critical vision of their own practices by comparing them to others, while emphasizing their specificities.

Diversity and interpenetration should also occur on the academic level. In their book, "Creative Marginality. Innovation at the Intersection of Social Sciences," Mattei, Dogan, and Robert Pahre argue for the interpenetration of disciplines and cultures. The exchange of such components as concepts, methodologies, discoveries, theories, perspectives, and academic journals raise new questions and objects of study for researchers and students[25]. Stein Rokkan considered that coming from another country (and society) makes people more aware of the cultural biases of scientific theories. It also reveals the arbitrariness of disciplinary boundaries by confronting us with the existence of varying forms of organization from one country to another. However, the authors note that migration is not always required. This is especially the case in "privileged locales in intellectual history," in which an entire community is able to reach a critical mass in a creative place, indicating that the fundamental feature is direct interaction among individuals involved in a creative culture. Mattei, Dogan, and Robert Pahre also propose a typology of innovative scholars, which reminds us that there are three kinds of innovative scholars: pioneers, builders, and hybrids. Innovation is thus possible even in "old" fields or subjects[26]. The potential wealth of creativity, innovation, and risk-taking behaviors and actions should not lead us to forget the negative impact they may have on the

[25] This idea is supported by historical examples of innovative scholars in the field of social sciences. Thorstein Veblen, author of *The Theory of the Leisure Class*, and one of the founders of the institutional economics movement, was born in Cato, Wisconsin of Norwegian immigrant parents. As a Norwegian-American sociologist and economist, he analyzed cultural marginality as a stimulus to intellectual creativity.

[26] This is particularly true in the social sciences, where, in the words of Howard S. Becker, "We never study the same thing twice because of the absence of any 'pure substance,' and the constantly moving political, social, cultural, economical, etc. context in which the phenomenon studied takes place."

creative individual if the environment does not promote originality[27]. One can consider that creativity is often conceived of as a source of disorder, thus sanctioned by the community, and that it might take time before an innovation is accepted. The authors eventually recognized that innovative scholars also exist among mono-disciplinary researchers, but consider that the latter may still be characterized as "wanderers," a status accompanying creativity, innovation, and risk-taking.

For its centennial, the Nobel foundation published a book entitled, "Cultures of Creativity," which contains eloquent examples of the difficulties scholars initially encounter upon introducing a creative idea. It is also clear from the study of places where Nobel prize winners have been abundant, that some of them are much more accessible to creative ideas. In such places, there is a critical mass of talented people who dare to take up important challenges. More recently, Carl Neuman wrote a paper entitled, "Fostering Creativity: A Model for Developing a Culture of Collective Creativity in Science," in which he reviewed the relevant literature and discussed the cultures of creativity that can be found in the EMBL,[28] which hosts scientists from all over the world trained in various disciplines. Interestingly, during independent interviews of group leaders, all described EMBL to be more conducive to creative research than most other places they knew, but many of them were more reluctant to discuss this publicly, as if creativity was still taboo among scientists.

Attitudes towards creativity and education

Different people or groups of people may have different attitudes towards initiative, creativity, and risk-taking. Whereas such behaviors are important in today's economy, one should not forget to also promote an ethical attitude in creativity and research (for instance, see the paper, "Risk: the ethics of a creative curriculum," by Janet Hargreaves). As stated in the Creativity in Higher Education report of the European Association of Universities:

> *"Creativity in itself is not necessarily good; there is ample historical evidence of scientific and technological innovations which have led to ethically disastrous consequences. At the same time, not everything that is ethical is creative.*

[27] In fact, because the fame of hybrid scholars may be in "foreign" disciplines, many of the most famous ones do not come from the most famous universities.

[28] (European Molecular Biology Laboratory)

However, linking creativity to ethics strengthens the concept in a number of ways. Doing what is right to the best of one's knowledge is, after all, one major precondition for higher education to fulfill its mandate towards society. In a more practical vein, by insisting that higher education institutions check any of their actions as to their potential ethical implications, project partners emphasized the importance of the "big picture" for decision-making. Taking all known factors into account is considered one of the standard "good practices" for identifying sustainable solutions. In turn, the lateral thinking which is required for doing this successfully is closely associated with creativity."

Furthermore, not every one will necessarily value education in the same way. Mickael Spence, a Nobel prize-winner in economics, developed a theory that is surprisingly similar to the handicap principle described above in the box. As summarized on the Nobel Foundation website:

"Spence's pioneering essay from 1973 (based on his PhD thesis) deals with education as a signal of productivity on the labor market. A fundamental insight is that signaling cannot succeed unless the signaling cost differs sufficiently among the "senders," i.e*., job applicants. An employer cannot distinguish the more productive applicants from those who are less productive unless the former find it sufficiently less costly to acquire an education that the latter choose a lower level of education."*

As described for the handicap principle, the costly signal indicated by a diploma is enough to be worth obtaining. Regardless of what may have been learned, it indicates an ability to work hard in a way similar to the way gene quality is advertised by the peacock's tail. Just as the tail may be useless, the diploma does not necessarily guarantee that the knowledge learned was useful to be selected for. The Red Queen principle may apply here too, since one is more likely to get a particular job by having more diplomas. This may explain the inflation of diploma observed when a specific diploma can guarantee access to a job in a one generation but not in the next, independently of the usefulness of the knowledge validated by the diploma for that job. Obviously, education can increase skills and creativity, but does not always have to do so; it is therefore worth keeping this analysis in mind when assessing education systems.

Academic study of creativity

Before we go on to discuss how creativity is considered in various systems, we will summarize what has been learned from studies of creativity. The academic study of creativity really took off in 1950. Much work in this field have since been published; for a review of various approaches, turn for instance to the collective work edited by Sternberg, "Handbook of Creativity." Academics need definitions, and creativity is often defined as the ability to produce novel work (*i.e.*, original and unanticipated) that is high in quality and appropriate (*i.e.,* useful and meeting task constraints.) Academic studies of creativity have evolved from former views that were mystical and psychoanalytical, and from pragmatic approaches that were not based on scientific methods, therefore not critically reviewed. Various disciplines have studied creativity, focusing on individuals, their motivations, their education, their interactions in the fields in which they developed their creativity, the various stages of creativity, their life-paths, and the societies in which they lived. These studies range from psychometric measurements conducted on individuals carrying out defined tasks, measuring parameters that could be relevant to creativity, to sociological and historical approaches that explain why creativity appears to vary in time and place in different societies. Hence, a whole range of methods developed in the social sciences have been used to study creativity. We will focus on the main conclusions that seem to have acquired a consensus and that seem most relevant in terms of their implications for fostering creativity in education.

What is required to be creative?

We may wonder whether creativity is reserved to geniuses who invent new applications, discover new scientific domains, and create new art forms, or whether everyone can be creative. Clearly, the answer to this depends on how the word *original* is defined. If it is taken to mean new for a given person, it does not lead to the same conclusion as if it applies to something that has never before been done by mankind. Obviously, the later definition of originality includes the former, and if one focuses on education, it would seem more useful to envision a continuum between creativity in toddlers and that in scientists and artists, placing them both in a developmental perspective. Cognitive scientists argue that creativity does not come from mythical muses[29], but to the use of normal cognitive processes that

[29] Interestingly, Elisabeth Gilbert, in her 2009 TED conference, "A different way to think

progressively mature with age and may be studied experimentally. Systematic studies of the lives of great achievers in many realms of human endeavor, such as those done by Mihaly Csikszentmihalyi in his book, "Creativity, Flow and the Psychology of Discovery and Invention," or the biographies of many Nobel Prize winners, argue also in favor of the progressive development of creative abilities. In some cases, precocious signs of interest in a field of study may occur very early, but this is not systematic, and in many cases, adult success has no clear connection to early ability. Nevertheless, among the most common points may be the ability to challenge oneself, to ask new questions, to be self-motivated, and to self-assess one's achievements without complacency. Csikszentmihalyi argues that such achievers derive so much pleasure from their favorite activity that they enter a state of "psychological flow," in which they can work for hours on end, further developing their skills. A key turning point is therefore to find what Ken Robinson calls *one's element*; the activity that so motivates an individual that he/she can remain in a state of flux or psychological flow while engaged in it. This state is often associated with the capacity to define one's own questions, one's own style, because intrinsic motivation is then at its greatest. Interestingly, the importance of intrinsic motivation was found to be associated with creativity within an educational setting, since, according to Teresa Amabile, this seems to be the key to the ability to do one's best.

Intrinsic motivation, knowledge, and creative thinking

Teresa Amabile argues that intrinsic motivation, which can range from interest in a subject to a passion for it, is one of the three essential components of the creative process. The other two are knowledge and a flexible and imaginative approach. She sees knowledge of the relevant material as necessary for a creative outcome, one must have a good knowledge of music to write an opera, and an intimate knowledge of physics to develop a new physical theory. However, knowledge may also be seen as a burden, and not all experts who possess a basic knowledge of a topic will use it

about creative genius," while recognizing the humanist heritage of the renaissance and the enlightenment, defends the importance of believing in the muses, the Greek demons, or the genius of roman antiquity. According to her, it is psychologically easier "to *have* a genius than to *be* a genius." Such mythical creatures helped relieve creative artists from the psychological weight of being creative, even after a success. For her, the artist should work hard and do his/her best, and creativity should not be considered a cause of stress when it is absent, but as a gift from the muses that allows the artist to achieve his/her most original work.

creatively. For those who are motivated to become experts, and who have been able to acquire the required knowledge, a flexible and imaginative approach will become limiting. As discussed by Karlyn Adams in a paper commissioned by the American *National Center on Education and the Economy*, many requirements have been proposed for creativity, all of which may be included in the above framework, which states that creativity is at the intersection between knowledge, intrinsic motivation, and an inventive attitude. Knowledge must include mastery of the state of the art of the subject, yet most of the time creativity will only emerge if mastery is combined with novel elements. As Karlyn Adams discussed,

> *"On one hand, in-depth experience and long-term focus in one specific area allows people to build the technical expertise that can serve as a foundation, or playground for creativity within a domain. At the same time, creativity rests on the ability to combine previously disparate elements in new ways, which implies a need for a broader focus and varied interests. Thus, perhaps the best profile for creativity is the T-shaped mind, with a breadth of understanding across multiple disciplines and one or two areas of in-depth expertise. Indeed, this is what Frans Johansson recommends in his book***,** The Medici Effect. *He explains, "we must strike a balance between depth and breadth of knowledge in order to maximize our creative potential," (Johansson, p. 104). He suggests that one way to improve breadth is to team up with people with different knowledge bases. The educational implications of this recommendation are perhaps in the realm of greater focus on interdisciplinary study and having students collaborate on group projects with team members of varied interests."*

Keith Simonton argues that creativity will initially increase with knowledge, but that this relationship may reach a plateau, then decrease. Howard Gardner observed that indeed, many creative people who have been able to achieve over different periods experience a ten-year interval between creative moments, since they need that time to acquire the expertise to be able to appropriately address a new problem. Knowledge may also limit creativity if not unlearned when it becomes obsolete (a neologism may be used: *obsoledge*, (obsolete knowledge), as Alvin Toffler put it,

> *"Much of what we're transmitting is doomed to obsolescence at a far more*

rapid rate than ever before. And that knowledge becomes what we call obsoledge: obsolete knowledge. We have this enormous bank of obsolete knowledge in our heads, in our books, and in our culture. When change was slower, obsoledge didn't pile up as quickly. Now, because everything is in rapid change, the amount of obsolete knowledge that we have -- and that we teach -- is greater and greater and greater. We're drowning in obsolete information. We make big decisions -- personal decisions -- based on it, and public and political decisions based on it."

Thus, we must teach how to learn to unlearn, as well as how to learn to learn.

Can one develop creative thinking and education?

In the "Handbook of Creativity" that Robert J. Sternberg edited, in which many theories of creativity are proposed, he offered a simple way of viewing creative thinking as having three main attributes: synthetic, analytical, and practical. The synthetic attribute may be seen as those moments when new ideas are generated by recombining previous ideas. The analytical attribute corresponds to those moments when ideas are evaluated by creative players, who should be able to discard the less relevant ones and focus on the most promising ones, then work on and further improve them. The practical attribute includes the ability to apply such ideas to real-world situations and to convince others of the relevance of the creative ideas. Sternberg argues that creative people are very much like venture capitalists, in that they are able to "buy early," *i.e*., to see the value of an idea that others do not, then improve it, and "sell" it for a high price, in terms of recognition.

In his 2003 review article entitled, "Creative Thinking in the Classroom," Sternberg first reviewed the discrimination that creative children suffer in the classical school classroom. He then described that creative teaching not only increases creativity, but also the skills that more traditional teaching is supposed to value, such as memorizing. He then very well summed-up the implications of research on creativity for education as well as the role of teachers, so it seems worthwhile to quote him at length:

In teaching students to process information creatively, we encourage them to create, invent, discover, explore, imagine, and suppose. However, we believe that, to a large extent, creativity is not just a matter of thinking in a certain way,

but rather it is an attitude toward life (Sternberg & Lubart, 1995, 1996). Creative people are creative, in large part, because they have decided to be creative (Sternberg, 2000). What are the decisions that underlie creative thinking? Perhaps there are at least 12 key ones.[30]

1. Redefine problems.
2. Analyze your own ideas.
3. Sell your ideas.
4. Knowledge is a double-edged sword
5. Surmount obstacles
6. Take sensible risks.
7. Willingness to grow
8. Believe in yourself
9. Tolerance of ambiguity.
10. Find what you love to do and do it
11. Allowing time.
12. Allowing mistakes.

Assessing intelligence and creativity

The synthetic, analytic, and practical attributes described above may clearly be seen as forms of intelligence that can be used in different domains. The relationship between intelligence and creativity has attracted the interest of many scientists. It would be good to have objective ways to measure the various components of intelligence and creativity, since it could help to better understand how to enhance them, as well as to design programs that could raise the quality of education. However, the issue has attracted a great deal of debate.

Some psychometric studies argue that there is a threshold effect for the interaction between intelligence (defined here as IQ) and creative ability, suggesting that above-average intelligence is required for creativity, but that beyond a given IQ, creativity is independent of IQ. Others have devised psychometric tests for creativity that also show it to be independent of IQ. The problem with such studies is to know how to measure both intelligence and creativity. Tests that assess some component of creativity, such as the ability to propose original solutions to standard problems, have been used. For instance, the Torrance test may be scored for originality of response (how unusual each response is), flexibility (how varied the responses are), and fluency (how many original responses there are), yet such tests can only measure a rather limited part of the creative spectrum. Thus, many people argue that their use

[30] The detailed description of these 12 key points may be found in annex 1; only their headings are cited here.

is better limited to research concerning those aspects of creativity, and that their systematic use in schools would be counter-productive. Even classic IQ tests are considered quite limited. In his books[31], Howard Gardner asks for the inclusion of the multiple dimensions of intelligence, which should measure other qualities than the logical and verbal IQ test does. Gardner also argues for integrating spatial intelligence, body-kinesthetic intelligence, musical intelligence, and two components of emotional intelligence, the ability to know oneself and to understand others' feelings. Sir Ken Robinson goes even further in "The Element". According to him, there are many more forms of intelligence and creativity, probably as many as there are human beings on the planet, thus it is not only pointless but also counter-productive to divide people between creative and non-creative. For him and other authors, such as Erica McWilliam, there is a danger in trying to define creative according to preset answers to standard tests[32]. An alternative would be to assess not a person's creativity, but the *product* of his/her creativity. Obviously, it is not so easy to assess the creativity of a work of art or of a solution to a problem objectively, but she explains that it appears that for a panel of experts independently judging a given product, the correlations are relatively good. While this may then help select candidates on the basis of the creativity of their past achievements, or assess them in a controlled manner (*e.g.*, test the effect of extrinsic motivation,) it is not scalable to compare, for instance, the systematic creativity of different education systems on a nationwide basis.

3. How can policies help?

The limits of traditional education

After reviewing the rate at which our environment is changing, the way natural systems adapt to rapid changes, and the lessons learned from social science studies of creativity, we will briefly look at how policies could affect the ability of the next generations of children to adapt to such ever-increasing changes. It is clear that different OECD countries have different policies concerning the importance of adaptability and creativity in education. For historical reasons, countries either have a centralized system with a nationwide curriculum or one that allows educational

[31] see for instance, Gardner, Howard. (1999) "Intelligence Reframed: Multiple Intelligences for the 21st Century." New York

[32] "Creative Workforce, How to Launch Young People into High-flying futures,"

policy to be conceived and implemented at the local level, and even at the individual classroom level if not tailored to the individual child. We will start with a brief historical perspective before describing different attempts that seem relevant for this topic.

Many authors, such as Ken Robinson, Anne Querrien, and Alvin Tofflery, argue that public education was designed to increase the skills and abilities of the new generations, while fulfilling the needs of developing industries. In addition to the official curriculum, which included the three “r”s (reading, writing, and arithmetic,) children who grew up in the countryside with much freedom, learned to remain silent and respect the authority of the teacher, to be on time, and to start and stop work at the same time as everybody else according to a fixed schedule cadenced by the ringing of a bell. The entire pedagogical system was teacher-centered, and little attention was paid to the specificities, needs, questions, motivation, talents, ability to take initiative, and creativity of the pupils.

The monitorial system as an early alternative

Interestingly, during the same period, in both in the French- and English-speaking worlds, an alternative strategy developed, partly because the above-described method required a number of teachers sufficient to oversee what students’ learned, which was relatively expensive. The monitorial system, or "*école mutuelle*," has been described by Anne Querien to lead to faster learning. According to the Wikipedia, it was…

> "…*based on the abler pupils being used as 'helpers' to the teacher, passing on the information they had learned to other students. The Monitorial System was found very useful by 19th century educators, as it proved to be a cheap way of making primary education more inclusive, thus making it possible to increase the average class size. The system is not entirely unlike the way professors, assistants and tutors work together in university education."*

Introduced in Europe in 1795 by Andrew Bell, who had encountered the concept in India, this system proved efficient, with children learning the program as much as twice as fast. However, in France, the system was replaced in 1832 by a nationally standardized curriculum run by teachers who were trained in an *école normale* ("normal" school, in which they were trained to teach the “norm” of knowledge.)

Teachers were subjected to “inspection” by a national corps, with respect to their conformity to the imposed curriculum. Since that period, and until recently, equivalent models have dominated in most of the world. Although the benefits associated with different educational approaches are periodically rediscovered in various places (*e.g.*, Tolstoi in Russia, and later Montessori in Italy, Freinet in France, Steiner in Germany, and Decrolly in Belgium,) they have remained alternative models and not mainstream for decades in industrial societies. Sometimes mutual teaching seems to reappear independently.

Modern alternatives

In French-speaking countries, mutual teaching has recently become popular; some eight hundred local programs have developed what they call "network of reciprocal knowledge exchange", which assumes three principles:

1. Everybody knows something,

2. No one knows everything,

3. From 1 & 2, we can see that everybody benefits by exchanging knowledge.

Interestingly, these pedagogical principles have been applied from primary school through Master’s and PhD programs. For instance, one can observe that disfavored children who failed in classical programs benefit from such an approach. They can gain self-confidence and rely on their ability to profit from knowledge acquisition and exchange when they discover they have skills that others do not have. At the other end of the education spectrum, talented young scientists can learn to be creative, take risks, and question knowledge much more readily when they interact with their peers. In France, the pioneer *main à la pâte* (hands-on) program championed by Nobel physics prize-winner Georges Charpak, allowing primary school children to discover science by experimenting, exploring, and debating, has been imitated in various countries.

Similarly, in Germany, interactions among students who learn by teaching (by being teachers themselves) are seen to facilitate foreign-language acquisition. This concurs with the ideas of Seneca, who during antiquity said that "by teaching we are learning." The modern version of mutual teaching is much improved, compared to the 19th century version, since now the teacher's role is to supervise interactions

among children within a well-structured framework. Students prepare by themselves at home and present their findings while interacting with each other. The initial peer interactions then undergo three more rounds consisting of individual work followed by deeper interaction.

In Italy, a most interesting experience seems to have resulted from a local initiative taken by parents in the city of Reggio Emilia after World War II. Since the inhabitants of that city wanted to promote education that would protect their children from fascism, and building on a tradition that included a role for the community in education, they developed innovative approaches to preschool and primary education. Even though this system has been now copied in many places, they refuse to call it a model, since one of its key aspects is that the creativity of teachers, and the capacity of that creativity to in turn foster creativity in children, be at the center of their philosophy of not wanting to enforce a stereotyped curriculum. Parents play an active role in Reggio schools. Trust, at all levels, and among all the actors, is an essential component of their philosophy, which also includes an original approach to cooking, food-sharing, the school, and the environment. They consider the environment to be the "third teacher" (after the parents and the human teachers,) which should be designed so as to foster new experiences, exploration, initiative, and creativity. Reggio-type schools have now been established in many countries, and the city of Reggio Emilia has founded a center to disseminate research and exchange on such pedagogies.

In the Spanish-speaking world, the most notable example of a successful alternative education is the *Escuela Nueva*, which originated in rural Colombia, making that country the first in which rural children have better results than those in cities. This program has attracted much attention from international organizations, foundations (such as the Clinton Global Initiative,) and local companies. It has spread to eleven countries and currently educates five million children. As *The Economist* described it,

> *"Under Escuela Nueva, the teacher's role changes from lecturing students to guiding their comprehension. Everything that the children learn must be relevant to their family and community. Firms are enthusiastic about the approach of Escuela Nueva to education because, among other things, it*

promotes core 21st century skills for contemporary enterprises, such as the ability to take the initiative and to work in groups."

The success of such initiatives show that with limited funding, well-designed programs can increase the quality of education and the ability to take initiatives, while maintaining a creative and open-minded attitude towards learning. However, in the countries mentioned above, systemic change has yet to become the subject of large public debate in a way that could lead to a systemic change.

Knowledge-building

Innovative methods of collaborative knowledge-building have been tested in 19 countries, based on theories developed in Canada by Marlene Scardamalia and Carl Bereiter[33]. According to them, this approach can have broad impact:

> *"Knowledge-building has been shown to yield advantages in literacy, in 21st century skills, in core-content knowledge, in the ability to learn from text, and in other abilities. However, it is a fact that knowledge-building involves students directly in creative and sustained work with ideas that makes it especially promising as the foundation for education in the knowledge age."*

The main principle is that in knowledge-building, work involved in the creation and improvement of ideas can be a source of learning. Adult knowledge-workers produce knowledge, simultaneously learning and updating their skills. Scardamalia and Bereiter argue that although achievements may differ, the same process can occur from the first grade to the PhD and after in working life, and that the software platform they developed, *Knowledge Forum,* can be adapted to all age groups. While engaging in these activities, knowledge-builders not only learn the facts they need to move the frontiers of knowledge as they perceive them, but also the meta-skills that are required, such as the ability to cooperate, create, and take initiatives. The practices they describe as "deep constructivism" increase many skills.

> *Overt practices, such as identifying problems of understanding, establishing, and refining goals based on progress, gathering information, theorizing, designing experiments, answering questions and improving theories, building models, monitoring and evaluating progress, and reporting are all directed by the participants themselves toward knowledge building goals.*

[33] Scardamalia, M., & Bereiter, C. (2003). Knowledge Building. In *Encyclopedia of Education. (2nd ed., pp. 1370-1373).* New York: Macmillan Reference, USA

Their approaches, followed on a larger scale in Hong-Kong, are summarized as follows:[34]

> *"Traditionally, schools are dominated by the teacher-led chalk-and-talk approach. Most of the time, there may not be enough time for students to discuss in class because of the tight teaching schedule and arrangement. In this circumstance, Knowledge Forum can provide room for students to have discussion and to develop their independent and critical thinking. Through the discussion and mutual learning process, students are actually forming a knowledge-building community. And in this community, students have to produce, share, and advance the knowledge of the collective. In this case, the roles of students have changed from that of clients to that of participants and workers in the community. Hence, there is a shift from teacher-directed approach to more student-centered learning. It helps trace out students' own paths of constructing knowledge collaboratively with the teacher's guidance and monitoring."*
>
> *The collaborative knowledge-building approach is very important to students, not only in the sense that it can help develop better thinking, analytical, enquiry, and problem-solving skills, but it also paves the way for students to develop their life-long learning abilities and attitudes. This works in line with the recent curriculum reform advocated by the Education Commission report on life-long learning towards the 21st century in Hong Kong, which emphasizes the importance of learning how to learn.*

When creativity & evaluation enters the public debate

Many initiatives have blossomed over the years in English-speaking countries, where the debate on education is fueled by many different contributions. The edutopia website (supported by Georges Lucas) reviews many of the most promising programs. There are also numerous books dedicated to the study of creativity in education. For instance, teachers can read "Creativity in the Classroom, Schools of Curious Delight," by Alane Jordan Starko; "Creativity in Education and Learning," by Arthur Cropley; and "Teaching in the Knowledge Society," by Handy Hargreaves[35]. The general public, including parents and students, can read "The Element," by Sir Ken Robinson, and policy-makers, managers, and academics will find much useful information in the "Creative

[34] http://lcp.cite.hku.hk/Literatures/KB/

[35] In these books, teachers will learn to teach in ways they were not taught. This is not necessarily obvious and may be one of the reasons education systems lag behind the fast changes of today's society. Teachers must build a capacity for cooperation, updating of their practices, creativity, change, and risk, in order to develop similar behaviors in children.

Workforce, How to Launch Young People into High-flying futures," by Erica McWilliam, which provides a clear description of the need to improve creative education in order to thrive in the digital age. In the meantime, in the U.S. and many other places, a culture of systematic evaluation of children, teachers, schools, and local governments has developed. It is easy to understand the motivation for assessing the results of schools: to encourage the best practices and to better understand what to include in a 21st century education. These evaluations, which are mostly based on multiple-choice tests, seem to have caused much "collateral damage," as described in a book by that title. Well-designed assessment can allow children to make progress and to develop their abilities, if they regularly receive constructive feedback. However, many scholars have argued that formatted, high-stake assessments, such as those developed by the Bush administration's "no child left behind program" can only drive everyone involved to do anything they can to "achieve" in those tests. Perverse effects result, such as cramming, focusing on preparing only for the tests and not on learning, and even cheating at all levels, including by children, teachers, schools, district educational *authorities, etc. As stated by a reviewer of this book, these effects are disastrous:*

"Collateral Damage: How High-Stakes Testing Corrupts America's Schools" powerfully details the destructive effects on education of high-stakes standardized testing. Authors Sharon Nichols and David Berliner construct their case around "Campbell's Law," named for researcher Donald Campbell:

> *"the more any quantitative social indicator is used for social decision-making, the more subject it will be to corruption pressures and the more apt it will be to distort and corrupt the social processes it was intended to monitor." When standardized tests are used for graduation and promotion decisions, or required by state and federal school accountability, both education and the meaning of test scores are corrupted."*

In northern Europe, a tradition of inquiry-based education has long been developed. In Denmark, for instance, children are evaluated not on rote learning of facts, but on their ability to express an original viewpoint on a subject that is debated at length in class. The Scandinavian countries happen to be leading in the international ranking,

both for their results in education and in innovation. One can see their well-articulated policy, in which experiments in pedagogy are not just the results of individual or school initiatives, but where there is a national policy that promotes such behaviors.

Finland as proof that education systems can be changed

Finland is an interesting case to study, since it went from a country that was internationally rated as average in 1988 to number one in the PISA ranking in 2001. According to the Pasi Sahlberg, a leading education specialist who worked for the World Bank and the European Training Foundation, several key factors seem to have been at play:

- During phase 1, an epistemological groundwork was built from 1988 to 1995, the main focus of which was to try to answer the questions, "What is knowledge? "What is learning?" Three complementary books published in Finnish helped teachers to understand first how the classical static conception of knowledge was inappropriate for the emerging knowledge society. The second book was dedicated to summarize research findings on education, teaching, and learning, and the third book built a bridge towards operational implications for teachers.

- Phase 2 began with educational reform that went from a centrally controlled national system prescribing and evaluating a given curriculum to a decentralized one with a national curriculum framework, which enabled building on the epistemological groundwork mentioned above. School curricula were then approved only locally, most often explicitly describing schools as creative places. Schools and teachers were invited to share their experiences in an open school improvement network, which all educators were invited to join, including those working outside schools, such as in scouting organizations and sports clubs. Teachers were required to earn Master's degrees and trained to experiment, basing their experiments on results obtained elsewhere. Former education inspectors, whose previous role was to ensure conformity to the curricula, became advisers, whose job was to help teachers develop creative curricula. Trust seems to have played a key role during this period. The government trusted the municipalities to manage the schools, the municipalities trusted the school boards, which in turn trusted teachers, who trusted the children (repeating is unheard of in Finland, and examinations are reserved for older

children.)

Probably not surprisingly, such broad reform was not without critics, yet, magically, most of them vanished overnight, when, in 2001, the first OECD PISA ranking was published. This ranking showed that Finland was doing best, not only in student achievement, which was already remarkable, but also in equity. (Despite the fact that decisions are made locally, Finland is the country with the least variation in achievement among schools,) in and economic efficiency (school budgetary expenditure is comparable to that in other OECD countries.) Interestingly, the Finns keep trying to innovate and further improve. Salhberg, for instance, has a dream for education. As he stated in a conference:

> *"My dream is not that one day every school will make adequate yearly progress, as measured by student achievement tests or anything similar. I have a dream that in the future, our schools, their students, and teachers can live in a culture of trust. I have a dream that one day our teachers can work in a spirit of responsibility rather than accountability. I have a dream that soon all our children will learn in truly enriching communities. School improvement has a key role to play in reaching out to this dream. At her murdered husband's funeral, Yoko Ono said: 'If you have a dream, it is just a dream, but if you share it with other people, it will become true.'"*

Following the Finnish philosopher, Pekka Himanen, Salhberg argues for "enriching interactions" among students, between teachers and students, and among teachers. For him, schools should therefore enrich communities with creative and competent people developing a creative culture of learning. Enriching interactions should allow everyone to be enriched by the interaction, which presupposes a culture of respect, trust, and freedom.

4. Where do we go from here? Main implications for measurement & policy

Assessing the environment

In closing, we will discuss the main implications for measurement and policy. Considering the current state of research, it is not clear whether a test that accurately measures initiative, risk-taking, and creativity in all their dimensions will ever be objectively and convincingly defined. Creativity is not measured easily, and even

less so in millions of individuals. ("Thinking out of the box" by checking boxes, seems at least to be a daunting challenge, if not a logical trap.) Given the importance of assessment in promoting changes in educational practice, short of some magical software, one may have to assess other components of creativity and risk-taking. If one cannot easily assess students' creativity, can one assess their creative environments? This seems like an interesting question for future research. Indeed, since creativity requires the ability to think differently, social interactions can easily destroy creativity. Parents, teachers, peers, and more generally, society as a whole, can either promote such differences or destroy creativity in all but the most resilient creative thinkers.

Research in these areas is less developed than the research described above, which is aimed at assessing some aspects of individual creativity. At this early stage, at least two parallel approaches can be proposed: individual polling, and evaluating the general role of discourse in creativity, particularly discourse on education.

Using individual polls, it would be interesting to not only assess people's perceptions of their own creativity, but also the way they see creativity in others, and perhaps the way they think about others' reactions to creativity. The potential differences in the answers to such questions could help us to understand whether the forces that slow the process of creativity are more embedded within individuals or within society. To be more explicit, let us take a simple, concrete example: One could ask a teacher how he/she would react when a student gives an unusual answer or takes initiatives or risks. The teacher's answers could be compared with the answer he/she would give if asked how an average teacher colleague would react to the same situation. It would be interesting to compare such answers at different periods and in different countries. Would there be situations in which, on the average, people would declare that they would react more positively to a creative attitude expressed by a student than by one of their colleagues? If so, it would be interesting to investigate the possible reasons for such paradoxes, in order to determine how to change the collective dynamics and individuals' attitudes, in the aim of promoting creativity.

Evaluating the role of discourse in creativity in different countries could be an interesting measure of the environmental attitude towards creativity. Is it part of daily interaction, part of the school curriculum, part of official discourse? Is it being

discussed online, and if so, in what types of websites (blogs, bookstores, official school sites, universities, government)? Can one apply for funding to study creativity or to develop creative programs? Can teachers use forums to discuss how to enhance creativity in their classrooms? Such indicators could then be correlated with other items already available in economics or education, such as innovation indicators, evaluation of students' ability in the PISA, and the percentage of jobs created that belong to what Richard Florida calls the "creative class."

If one takes the example of Finnish achievements in terms of education and innovation, and the fact that an important epistemological debate and the publication of influential books that anyone can read all predated these successes, it may well be that such comparisons provide important lessons. Indeed, having a dynamic view of these indicators would be even more convincing, so ideally such data should be available over extended periods. For instance, if official discourse is shown to influence discussions place among teachers, which in turn has an impact in the classroom, one would hope that ministers of education and government leaders would address the subject publicly. If the availability of books in the national language were shown to be a key determinant in promoting healthy debate on how to promote creativity, initiative, and risk-taking among students, the promotion of good practices could be accelerated by encouraging the publication and translation of foreign books on the subject. If it were shown that countries benefit from research and scientific assessment of creativity related classroom practices, this could lead to collaboration, improved understanding, and adapting the best practices.

Creativity in higher education

At the university level, such international discussions have taken place, and have resulted in specific recommendations concerning creativity in higher education (for instance, see the report of the European Association of Universities on how to foster creativity in higher education.) This report emphasize the importance of background diversity. Indeed, varied geographic and social origins promote creativity; therefore policies that favor cross-border exchanges and social mobility should be favored. The report also recommends hiring of *"*unconventional teachers*"* and

> *"the establishment of interdisciplinary "doctoral schools" may be a suitable structure for transcending traditional disciplinary boundaries. Moreover,*

allowing for electives from a wide variety of disciplines would encourage diversity on the curricular level. Offering students the opportunity to spend some time in placements with external partner organizations related to their degree studies can be another way to create a diversity of learning environments for them."

Some efficient interdisciplinary solutions that promote both the breadth and depth of knowledge have been encountered in higher education. The diversity of disciplines taught, including major and minor concentrations, or courses and projects targeted to the interfaces between fields, allow students to discover approaches developed by a range of individuals working in different fields. It can also help them to find the approach that best suits their abilities and wishes, although this would require practical and field activities not yet included in all such programs. Fieldwork or laboratory experience should be a central part of research programs, in order to promote student interest and to confront them with practical situations requiring specific answers. Solutions may be proposed that promote original approaches to old subjects and objects, by encouraging cross-disciplinary studies. For example, the division of undergraduate education into major and minor subjects allows students to benefit from very different teaching approaches and analyses. The possibility to change orientation and enter a graduate program without necessarily having fully completed the corresponding undergraduate program is another way to promote a diversity of views and analysis among students. By providing such students additional courses so as to build a theoretical base for their future studies, the diversity of approaches will be increased, thus fostering creativity and innovation. In addition, this would promote risk-taking among students, since they would more easily dare to study marginal disciplines, knowing that they could always go back to the mainstream after having explored a singular, individual path among the various disciplines, one that is likely to contribute to their own style and creativity[36].

They also argue in favor of transcending classical, one-way teaching, passive listening, and hierarchical relationships; they promote creativity by implementing new teaching schemes, including discussion classes, study circles, learning by doing, and

[36] Think of Steve Jobs study of caligraphy that according to him is one of the reasons Apple design is different from those of its competitors.

debate cafés. For the European Association of Universities, evaluation should be geared more toward the ability to change and promote a creative atmosphere than toward past achievements. University should become "living organisms," who learn from past successes and mistakes, applying their creativity in order to adapt to a constantly changing environment. No doubt, many of these recommendations could not only improve teaching in universities, but also in high-schools and primary schools. Indeed, in "Creativity in the Classroom, Schools of Curious Delight," by Alane Jordan Starko, teachers of younger students can find many similar proposals and practical tips and that help them to promote creativity in their classes.

Rethinking education

Thus is seems clear that from an analysis of the literature and various national systems that creating a creative workforce cannot be achieved without making a huge effort to rethink education. We need to construct education systems that empower children, students and adults to take responsibility; that enhance the number of responsible, innovative, free minds that will contribute to seeking solutions to the local and global issues we are facing.

The quality of education can only be improved by developing a culture of questioning and creative thinking**.** As any researcher knows, asking questions and creating new concepts is key in the progress of science. Too often however, only scientific *conclusions* are taught, to the exclusion of the process of Socratic questioning and creative thinking that are at the roots of knowledge. These processes of inquiry that can be learned by discovering how science works are sufficiently generic to offer any citizen the freedom and the tools needed investigate his/her environment and to devise creative solutions for improving it. In today's knowledge society, one should not just memorize facts (which can be found in books or on the web,) but rather express one's own viewpoint, systematically questioning and seeking creative solutions to global problems. While much has been accomplished, there is no unique way to attain this goal of empowering the citizens of tomorrow and enhancing creativity through education. We believe that educators and educational institutions in all OECD countries should make space available for educational experimentation, supporting and funding such experimentation, learning from the results. Conceptual reflection may complement such an approach, but should not be the only bring about

change; national and international debate must be promoted that leads us to try, evaluate, and encourage the best practices, implementing a network of educational experimentation that should:

- Creatively question existing systems;

- Suggest frameworks for experimentation;

- Suggest ways to make the knowledge flow across borders and become adopted by national and international institutions, thus go beyond the experimental stage;

- Encourage teachers to spend time thinking about how they can promote creativity, risk-taking, and initiative in their classrooms, and to discuss their experiences and results with their colleagues.

Studies of such education systems that could lead to evidence-based reforms are advocated by C. Wieman another Nobel Prize-winner, who argued for a reform of science education:

> *“Science students are leaving their courses seeing the science as less interesting and relevant than they did when they started. The typical student is not learning to see the science like an expert, as a set of interconnected experimentally determined concepts that describe the world.”*

In their paper, "Re-designing Science Pedagogy: Reversing the Flight from Science," Erica McWilliam and her colleagues argue for taking action to reverse current trends that are leading to a reduction in the number of science students in most developed countries. Their review of the literature led them to them conclude:

> *"Young people are more engaged by active tasks than with a passive consumption approach to transfer of core knowledge. It is boredom, not rigor, that disengages them—the difference between static and dynamic sources of knowledge. Creativity is not the antithesis of scientific rigor but the core business of scientific thinking. We now have new understandings of creative pedagogies that make teaching strategies visible and effective. These strategies can build academic, digital, and social capacity simultaneously, and this is the new core business of the science educator."*

Actually, the above statements could apply to education in all domains, and not just science, indicating that while further research must be undertaken, action and policy should not be further delayed. Considering the importance of creativity, risk-taking, and initiative in education, one should not wait for later results, but begin to implement national and international programs. Such programs should favor creativity and maximize dissemination of knowledge acquired about creativity, by promoting the translation and dissemination of works on the subject, the creation of creativity courses for teachers, students and workers, and the development of websites in which teachers can exchange their experiences.

Time and places of creativity

To further promote creative exchanges, a good approach would be to create modern "salons;" creative places dedicated to free interaction among like-minded creative people who have time to devote to generating new ideas. In such places, the basic philosophy should be what a Japanese proverb says, "none of us alone is more intelligent than all of us together." This highlights what has been confirmed by studies such as Dunbar's immersion in research laboratories: that creative ideas come from repeated interaction among many open-minded and diverse brains that have learned to trust each other and collaborate. Thus, it would be key to educate students to cooperate and exchange ideas in a a friendly mode among themselves, and then refine their output. One should therefore teach students to criticize others' ideas without criticizing those who advance the ideas, then to help them to improve those ideas by enriching them with their own. Today, the creation of hubs where ideas can flow freely plays a key role in the development of collective intelligence. These creative spaces may be virtual or real places, but they must be developed -- not just to socialize -- but to interact in a way that promotes creativity and the free flow of ideas. Students should be encouraged to use their on-line time to maximize creative interaction (new generations of websites that maximize the use of existing tools and to invent new ones are likely to be developed for just that purpose). It is very likely that some of the most promising interactions that emerge on-line will be followed by real-world meetings in places created to foster creative interaction, or in more traditional spaces "squatted" by creative people eager to exchange their most recent ideas (coffee shops, cafeterias, in front of vending machines and photocopiers, often create the serendipity needed to increase the likelihood of

encounters of creative minds outside formal meetings).

If the past century-style university is affected by the development of online resources and web-based universities, we can be sure that one of its major assets is the campus, since the best organized universities behave like gigantic sites of creativity, where ideas are discussed day and night among motivated students and teachers from all over the world. For an idea of the economic potential of such interactions, one might look at the founders of high-tech companies that started out with nothing and within a decade generated more than twenty billion dollars or employed more than 10,000 people. Sixty-four percent of them were created by students from Stanford and Berkeley and 73% are located on university campuses in California. Two-thirds of these students came from other countries and were attracted to the campuses by the creative atmosphere they knew they could find in them.

Being able to create hubs for creative minds should become a priority for any country that wants to stimulate the next generation of ground-breaking innovation. Furthermore, the average age of the founders of these companies was twenty-six. This alone tells us that what educational policy can do prior to such a young age is clearly essential in maximizing creativity in the next generation and helping them to invent the future. The example of creative innovators, such as Steve Jobs, the founder of Apple, shows that time is what such creative education needs most in order to blossom, so any curriculum that favors cramming cannot lead to creativity. On the contrary, creative projects should be organized during periods when students can freely devote their time to them.

Educating creative knowledge builders

The impact of these measures could lead to the training of creative knowledge-builders, who would be educated to become "21st century autodidacts". It may seem contradictory to train autodidacts, but nearly twenty-five centuries ago, Socrates already realized that the goal of education is to trigger "the fire that is inflamed by a spark that then feeds itself." With Internet access, search engines, and ever-better open education resources, the fuel for this fire is now limitless; so the role of teachers in fostering the initial spark and in educating these children to become adults who will update their knowledge themselves is even more important. We must all adapt to societies that are evolving ever faster, since in many fields like science and

technology the quantity of new knowledge doubles every few years. Already, each of us must manage an growing stream of information to keep abreast of progress in our areas of interest and skills, to be most effective in our professional or social life. It is essential to learn to master these flows of information and the innovations they enable. As Socrates also said, "writing cannot grasp knowledge, because, contrary to information, knowledge does not exist outside of humans." Hence, the role of the educator should be to help students transform that information into knowledge. In the recent collective book, "Opening-up Education, The Collective Advancement of Education through Open Technology, Open Content, and Open Knowledge, edited by Toru Iiyoshi and M. S. Vijay Kumar, the authors conclude by arguing that today, teachers should become *"education sommeliers" who help select from a variety of options, and as facilitators of group work, as well as providers of interactive environments, become agents of effective, responsive, and appropriate learning opportunities."*

Concluding remarks

A review of the literature cited in this report reveals that solutions exist that have been validated by research and by experience in pioneering schools, including many that do not always work under favorable conditions. As stated by a teacher cited in the closing lines of "It's Being Done," by Karin Chenoveth,

> *"we know what works in education, the research is prolific; amazingly then, the question today is not about what works but about why we do not implement what we know works in all school for all kids."*

Promoting the dissemination of best practices by creating environments and cultural conditions in which they can spread should thus be the priority of education policy. To develop meta-skills, such as creativity, risk-taking, and the ability to take initiatives, policies should free teachers to be creative and take initiatives, allow them to exchange ideas with each other, and to learn the results of successful practices. Although teacher-training is essential, it will not suffice to trigger the required changes if national debate is not promoted by all available means. These include commitment by the highest authorities, publication of books (including translations, if need be,) television and radio programs, and creation of websites and conferences

aimed at creating public debate on how to educate children so as to allow them to face the challenges of a world that changes too fast for any one to predict.

From the evidence reviewed in this report, one could conclude that since coming generations will have access to ever more information and tools for dealing with such information, their teachers must also show them how to learn, unlearn, create, organize, prioritize, critically analyze, and decide whether to reject or integrate information. In the future, all children, all students, all citizens should be 21st century knowledge-builders, able to update their skills on their own. They will also learn to take initiatives -- and sometimes risks -- combining these new skills to create innovations available to all of society. Education should make them feel confident enough in their creativity to see these changes as opportunities to be seized, not as threats. So that everyone can benefit from ever-faster technological progress, children and adults via lifelong learning must be taught the ability to learn independently, to collaborate with others, and to maximize their creative abilities. To make this possible, schools and universities must be among the first places of creativity, in which children and adults can develop their potential. In the coming years, we can be sure that countries which mobilize the collective intelligence of their citizens by means of creative education systems will be at the forefront of human development and technology.

Annexes

Annexe 1: Excerpts from "Creative Thinking in the Classroom", by Robert J. Sternberg

In teaching students to process information creatively, we encourage them to create, invent, discover, explore, imagine. and suppose. However, we believe that, to a large extent, creativity is not just a matter of thinking in a certain way, but rather it is an attitude toward life (Sternberg & Lubart, 1995, 1996). Creative people are creative, in large part, because they have decided to be creative (Sternberg, 2000). What are the decisions that underlie creative thinking? Perhaps there are at least 12 key ones.

1. Re-define problems. Re-defining a problem means taking a problem that most people see in one way and allowing, and even prodding oneself, to see it in another way. It means not simply accepting things because other people accept them.
2. Analyze your own ideas. No one has only good ideas. Even the most creative psychologists sometimes make mistakes. Students need to learn to critique their own ideas; to be the first to decide which of their ideas are really worth pursuing and, later, to admit when they have made a mistake. Everyone should retain a healthy degree of skepticism about any idea he or she has. No one is right all the time, and people who lose their skepticism about their own ideas may quickly reach dead ends, because they may believe they have all the answers.
3. Sell your ideas. When we are young, we may believe that creative ideas sell themselves. They don't. The creative process does not end with their generation, or even with their being critiqued. Because creative ideas challenge existing ways of doing things, they must be 'sold' to the public, whether scientific or lay.
4. Knowledge is a double-edged sword. To be creative, one has to be knowledgeable: one cannot go beyond what is known without knowing it. However, knowledge can also impede creativity (French & Sternberg, 1989). Experts can become entrenched in ways of seeing things, and lose sight of other perspectives or points of view. It becomes important, therefore, for teachers to impress upon students that students have as much to teach teachers as teachers have to teach students. The teachers have the advantage of knowledge, the students of flexibility. Working together, they can accomplish more than either can on their own. Teachers have to be especially careful that they not dismiss students' views simply because the views happen not to fit into their own views of the world. On the one hand, one cannot be creative without knowledge. Quite simply, one cannot go beyond the existing state of knowledge if one does not know what that state is. Many children have ideas that are creative with respect to themselves, but not with respect to the field, because others have had the same ideas before. Those with a greater knowledge base can be creative in ways that those who are still learning about the basics of the field cannot be. At the same time, those who have an expert level of knowledge can experience tunnel vision, narrow thinking, and entrenchment. Experts can become so stuck in a way of thinking that they become unable to extricate themselves from it. Such narrowing does not just happen to others. It happens to everyone.

Learning must be a lifelong process, not one that terminates when a person achieves some measure of recognition. When a person believes that he or she knows everything there is to know, he or she is unlikely to ever show truly meaningful creativity again.

5. Surmount obstacles. Because creative people 'defy the crowd,' they inevitably confront obstacles. The question is not whether they will confront obstacles, but whether they will have the guts to surmount them.
6. Take sensible risks. Our educational system often encourages students to play it safe. On tests they give safe answers. When they write papers, they try to second-guess what their professors want to hear. But creative people always are people who are willing to risk something and, in the process, fail some of the time in order to succeed other times. Teachers need to encourage such risk taking.
7. Willingness to grow. Many people have one creative idea early in their career and then spend the rest of their life unfolding that idea. They become unwilling or even afraid to go beyond that idea. Perhaps early on they fought the scientific or other establishment to win acceptance of that idea. Later, they become that establishment, fighting against the new ideas that threaten their own self-perceived monopoly on truth.
8. Believe in yourself. Creative people often find that their ideas get a poor reception. I suspect that all truly creative people come to believe, at some time or another, that they have lost most or all their external sources of intellectual and even emotional support. At these times, in particular, it is particularly important that they maintain their belief in themselves, to maintain a sense of self-efficacy (Bandura, 1996). If they lose this belief, they will find themselves with nothing.
9. Tolerance of ambiguity. When we try creative things, we often find that in their early or, even sometimes late stages, they do not work out the way they seemingly should. We go through prolonged, uncomfortable stages of ambiguity where things just do not quite fall into place. Yet, in order to be creative, we need to tolerate ambiguity long enough to get our ideas right.
10. Find what you love to do and do it. If research about creativity shows anything, it is that people are at their most creative when they are doing what they love to do (see, for example, Amabile, 1996). As teachers, therefore, we need to encourage students to find their own niche, their own love of psychology or anything else, and not to try to turn them into disciples or 'intellectual clones' who will do 'our thing' rather than their own.
11. Allowing time. Being creative takes time (Gruber & Wallace, 1999). The view that most creative inspirations come in an isolated flash simply is not correct. Students need to learn to allow time for incubation, reflection, and selection among alternative ideas. If they always rush, or are rushed, they will have difficulty producing creative work.
12. Allowing mistakes. People learn from their mistakes. However, if children become afraid to make mistakes, they will have trouble being creative. Creative people often have many failed ideas or products along the way to their successful ones. Had they not had the opportunities to make these mistakes, they perhaps never would have generated the idea or product for which they became well known.

Annexe 2 : About the author

François Taddei heads the Evolutionary Systems Biology team at a unit of the French National Institute of Health & Medical Research (INSERM) in Paris-Descartes University's Medical School. After a generalist scientific education, with majors in physics and biology at the *École Polytechnique*," he became a tenured higher civil servant at the French Ministry of Agriculture, before earning a PhD in genetics, studying the evolution of the rate of evolution with Miroslav Radman. After postdoctoral training with John Maynard-Smith, for the last 10 years, his research team has been studying innovation and degeneracy in biological systems. This work has produced many publications in generalist scientific journals, and has been recognized by several awards, (the European Young Investigator award, the Human Frontier Science Program award, the INSERM Award for Fundamental Research, and the Liliane Bettencourt Life Science Award).

Over the last five years, he has created the CRI (Center for Research and Interdisciplinary) in Paris, which offers a Master's degree (Interdisciplinary Approaches to Life sciences, AIV), a doctoral school (Frontiers of Life, FdV), supported by the Liliane Bettencourt PhD program), and holds chairs funded by Orange and Axa. CRI's dedicated facilities host visiting professors and several student discussion clubs, which meet biweekly. CRI's main role is to promote new pedagogies to help creative students take initiatives and develop their research projects, with the help of mentors, research institutions, private companies, and foundations, such as the Bettencourt Foundation, which has supported many student-created activities. These activities range from the first French synthetic biology team (which won the Foundational Research Award at its first participation in the MIT-sponsored iGEM competition) to the "Paris-Montagne" science festival and the "Science Académie," an outreach program that allows high schools students from disfavored neighborhoods to discover the creativity of science while spending their vacations in research labs.

Acknowledgements

The author thanks the following people for their helpful contributions that improved this report but assumes full responsibility for any shortcomings in it.

Livio and Eva-Fleur Riboli-Sasco have helped since the beginning in identifying key references and discussing the work. Comments by Ariel Lindner, and Dominique and Julia Taddei have improved previous versions of the manuscript. Noah Hardy edited the manuscript. Last but not least, Erica McWilliam and Pasi Sahlberg were kind enough to share some of their unpublished work and ideas, which has enriched the report.

References

Adams, K., *American National Center on Education and the Economy.*

Aghion, P., et al., *Endogenous growth theory*. 1998, Cambridge, Mass.: MIT Press. xiii, 694 p.

Creativity in Higher Education report, E.U. Association, Editor. 2007: Brussel.

Cropley, A.J. and D. Cropley, *Fostering creativity : a diagnostic approach for higher education and organizations*. 2009, Cresskill, NJ: Hampton Press.

Csikszentmihalyi, M., *Creativity : flow and the psychology of discovery and invention*. 1st ed. 1996, New York: HarperCollinsPublishers. viii, 456 p.

Dewar, J.A., *The information age and the printing press : looking backward to see ahead*. 1998, Santa Monica, CA: RAND. 30 p.

Dogan, M. and R. Pahre, *Creative marginality : innovation at the intersections of social sciences*. 1990, Boulder: Westview Press. x, 278 p.

Don't fear the Robot Scientist. Nature, 2004. **427**(6971): p. 181.

Hargreaves, A., *Teaching in the knowledge society : education in the age of insecurity*. 2003, New York: Teachers College Press. x, 230 p.

Hargreaves, J., *Risk: the ethics of a creative curriculum.* Innovations in Education and Teaching International, 2008. **45**(3): p. 227-234.

in *The Economist*.

Johansson, F., *The Medici effect : what elephants and epidemics can teach us about innovation*. 2006, Boston, Mass.: Harvard Business School Press. xiii, 207 p.

Larsson, U., *Cultures of creativity : the centennial exhibition of the Nobel prize*. Nobel Museum Archives ;. 2001, Canton, MA: Science History Publications. 228 p.

Lefebvre, L., S.M. Reader, and D. Sol, *Brains, innovations and evolution in birds and primates.* Brain Behav Evol, 2004. **63**(4): p. 233-46.

Liyoshi, T. and M.S.V. Kumar, *Opening up education : the collective advancement of education through open technology, open content, and open knowledge*. 2008, Cambridge, MA: MIT Press.

McWilliam, E., *The Creative Workforce: How to launch young people into high-flying futures*. 2008: UNSW Press.

Neumann, C.J., *Fostering creativity. A model for developing a culture of collective creativity in science.* EMBO Rep, 2007. **8**(3): p. 202-6.

Plotkin, H.C., *Darwin machines and the nature of knowledge*. 1994, Cambridge, Mass.: Harvard University Press. xviii, 269 p.

Price Derek John de Solla., *Science since Babylon*. 1961, New Haven,: Yale University Press. 149 p.

Querrien, A., *L'école mutuelle : une pédagogie trop efficace*. 2005, Paris: Empêcheurs de penser en rond. 181 p.

Robinson, K. and L. Aronica, *The element : how finding your passion changes everything*. 2009, New York: Viking. xiv, 274 p.

Sahlberg, P., *Education policies for raising student learning: The Finnish approach.* Journal of Education Policy, 2007. **22**(2): p. 147-171.

Scardamalia Marlene and C. Bereiter, *FCL and Knowledge Building: A Continuing Dialogue.* 2006.

Starko, A.J., *Creativity in the classroom : schools of curious delight*. 1995, White Plains, N.Y.: Longman Publishers USA. ix, 342 p.

Sternberg, *Creative Thinking in the Classroom.* Scandinavian Journal of Educational Research, 2003. **47**(3): p. 325-338.

Sternberg, R.J., *Handbook of creativity*. 1999, Cambridge, U.K. ; New York: Cambridge University Press. ix, 490 p.
Toffler, A., *Learning for tomorrow; the role of the future in education*. [1st ed. 1974, New York,: Random House. xxvi, 421 p.
Wills, C., *The runaway brain : the evolution of human uniqueness*. 1993, New York, N.Y.: Basic Books. xxiv, 358 p.
Wilson, E.O., *Consilience : the unity of knowledge*. 1st ed. 1998, New York: Knopf : Distributed by Random House. 332 p.