The current education system was designed in the 19th century to support the first industrial revolution. Does it still meet the needs of the 21st century?

Rethinking education

By KOEN DE BOSSCHERE and TULLIO VARDANEGA

The education system as we know it was designed in the 19th century to prepare the workforce for the needs of industry and government, as understood at the time. The basic concept has not fundamentally changed in the last 150 years. It worked well, provided that (i) people had lifelong jobs for which they could be trained at a young age, and (ii) knowledge was mostly shared via specialized books and libraries and changed slowly.

Today, (i) schools can no longer prepare the students for a lifelong career, and (ii) the ease of internet access and use has shattered schools' strict monopoly on knowledge dissemination. This has profound consequences for the future of education, which should be focused less on delivering static degrees of competence, and more on flexibility, self-directed learning, entrepreneurship and innovation. At the same time, while much younger in age, computer science and computing engineering education also have to change in order to encompass more profound awareness of the changes that informatics and digitalization are having on the very fabric of our society.

Key insights

- Schools have lost their monopoly on teaching; the internet has become one big international school: affordable and open to everybody, 24/7.
- The current education system was designed to serve 19th century industry and society, and it has to adapt to serve the needs of the 21st century.
- Schools can no longer educate people for a whole career; they can only educate people for their first job. Lifelong learning is essential for individuals to stay relevant in the job market, and to keep Europe competitive.
- High-quality education is a crucial element of sovereignty. If the European Union (EU) cannot produce enough local graduates with the right skills, it will not reach full sovereignty but will have to depend on foreign resources. In order to reach digital sovereignty, the EU needs enough information and communication technology (ICT) workers.

Key recommendations

- Modern education should be a mix of formal and informal learning, coaching students to become T-shaped professionals who serve the economy and society in the 21st century. All graduates should have basic digital skills.
- The EU should work to ensure a sufficient supply of world-class computer science and computer engineering courses, as well as ways to retain talent trained in Europe. Unconventional routes to technology careers should also be considered to broaden the talent pool.
- Universities should take on two important additional roles: lifelong learning and supporting regional entrepreneurial ecosystems.
- It is time to develop digital ethics as a separate discipline and to integrate it into higher education curricula.

The evolution of compulsory education

Compulsory education has a long history. In Europe, it started in the 16th century with the Protestant Reformation in Germany, where Martin Luther called for compulsory schooling in order to make sure that Protestants could read the German translation of the Bible by themselves. In the 17th century, several Protestant territories in Europe and the North American colonies implemented compulsory education for both boys and girls. The first state-wide compulsory education system was installed in Prussia in 1763 (for all children aged five to 13).

Around the same time, Prussia also invested in the creation of modern universities that used German as the language of instruction, chose rationalism over religious orthodoxy, applied new modes of teaching, and gave significant freedom to the professors (academic staff) who could also spend part of their time on research. The universities became the centre of the German Enlightenment in the 17th and 18th centuries [1].

Unleashing the intellectual power of the smartest people led to an unprecedented series of leaders in all areas of human cognition in the German-speaking world: Bach, Mozart, Schubert, Mendel, Freud, Engels, Marx, Kant, Nietzsche, Bonhoeffer, Ratzinger, Euler, Gödel, Gauss, von Liebig, Kekulé, Koch, Clausius, Boltzmann, Hertz, von Helmholtz, Röntgen, Planck, Einstein, Goethe, Schlegel, Hegel, van Beethoven,

von Humbolt, Schiller... This intellectual development also led to many technological innovations [2].

In the 19th century, compulsory education became mainstream in most Western countries and was universal by the time of the Second World War. Compulsory education was no longer inspired by religion, but by the needs of the industrial revolution: the availability of lots of workers with the right skillset. This explains why the modern compulsory education system was organized like a factory assembly line: children all entered at the same age and, year by year, they learned a standard set of facts, skills, competences and attitudes. Children and adolescents were also disciplined as if they worked in a factory: schools were run according to a strict daily and weekly schedule; arriving late at school was not permitted. There was also quality control: if they failed the test for a particular year, they had to retake the year, or switch to a different track. Some countries established standardized tests at crucial transition points in the name of "guaranteeing" quality. Out of such schools came a steady stream of standardized and government-approved workers: doctors, lawyers, teachers, nurses, construction workers, mechanics, ICT workers, …

In every country, public education is a very important department of government because it is not only large scale but also politically sensitive, as this is the place where future generations are being formed, and where the future of society is shaped. The focus often depends on the government that is in power: there may be more or less focus on nation building, on integration of under-represented groups, on STEM education, on religious or cultural studies, on entrepreneurship, on excellence, …. Furthermore, many countries honour freedom of education, which means that parents have the right to have their children educated in line with their personal views (political, religious, social, language, …) and without intervention of the nation state (i.e. via private schools or home schooling). In the 20th century, a number of governments experienced difficulties because they could not agree on education policy [14].

At the transition between the 20th and 21st centuries, the education model has changed minimally: (i) compulsory education has been extended in most countries (lowering the age of entry and raising the age of completion to 18), and (ii) the body of knowledge designed for learning has been continuously updated. In an evolution that started after the Second World War, many students started higher education because secondary education was no longer considered a sufficient basis for a well-paid career. Today, for many young adults, their formal schooling ends when they obtain a bachelor's or master's degree. The number of PhD students has also increased over the last 50 years, leading to increasing numbers of doctoral degrees. This model has served society and industry very well over the last 150 years, allowing countries to exploit the intellectual potential of the population.

Schools are no longer the only option for education

Schools focus on formal learning: the teachers explain the material, and the pupils prove that they understand it via testing. Eventually, pupils obtain a diploma that proves that they completed a particular study programme. Schools have a historical monopoly on formal learning but, with the rise of the internet, they now have strong competition [8,9].

The under-18s of today do a lot of non-formal (structured learning outside school, e.g. learning to play a musical instrument) and informal learning (in daily life) about their interests, hobbies and the world around them. A significant amount of non-formal and informal learning happens on the internet, which offers many opportunities for self-directed or incidental learning. The material is often presented in a way that is both very attractive (short movies, animations, games, demos, …) and fun, and does not feel like learning.

In Europe, the complete educational track from preschool to final graduation is funded by the government (at least for the public schools). Governments often start funding educational places for children aged two to three years, when they enter preschool, until they obtain their highest degree: up to 20 years in the case of a master's degree. Such a period equates to almost 50% of the span of a full career; it hence represents a huge societal investment in every single newborn.

Some countries allow universities to charge tuition fees to cover part of their costs. In countries with high tuition fees, it is common to finance a higher education degree with a student loan that has to be repaid. The offering on the internet is available 24/7, and is very cheap compared to the cost of schools. It is an attractive option for people who cannot afford the classic option. The offering is overwhelming in its breadth and range, and is growing daily.

Future education will be a mix of formal, non-formal and informal learning

Change is accelerating; there are no longer lifelong guarantees. Today's globalized world has been described as VUCA: volatile, uncertain, complex and ambiguous [13]. Unfortunately, schools are all but VUCA: they are usually structured and predictable, they often simplify things and avoid ambiguity, they offer a protected environment for students. This is quite different from the real world.

Despite this, schools do not work equally well for all pupils. Teaching may progress too fast for some, too slow for others. Some have problems with strict daily and weekly routines, and some encounter difficulties when they hit puberty. The one-size-fits-all model is not the best choice for all children. Thanks to freedom of education, parents who can afford to do so may decide to send their children to a private school, which may be able to offer a more personalized education.

In the real world, the evolution of science and technology goes at breakneck speed, and the knowledge base delivered by school education is rapidly and increasingly proving insufficient. What is certain is that it will not serve a complete career. Today, the half-life of knowledge in some disciplines is less than 10 years [3]. Much of the information that people learned in school 20 years ago has been refuted by new scientific insights. As a result, learning cannot stop with graduation. Adults will

have to further develop their knowledge and competences throughout their lifetime.

Obviously, we cannot send adults back to school to update their knowledge after a number of years. Instead, we must work with non-formal learning and informal learning. But then the question is: why wait until graduation to start lifelong learning? And why not start much sooner with non-formal and informal learning? In other words: is 20 years of uninterrupted formal education the best preparation for a career in the 21st century? If it isn't, which things should be part of formal education, and which could be part of the non-formal and informal education of children?

Formal education might be the best option to learn the basics of the established disciplines: mathematics, physics, biology, chemistry, languages, history, culture, economics, …. When studying the basics, study programmes should not focus too much on teaching solutions (which are by definition changing), but instead focus on reasoning and on the fundamental principles of the discipline, which have a much longer half-life. Furthermore, it is the fundamental principles that are needed to develop outside-the-box solutions in the future. Learning about the solutions can be done more easily in a non-formal or informal learning setting by reading, watching documentaries, and undertaking internships and voluntary work, often on a need-to-know basis in the context of project work. Making students partially responsible for their own education will lead to them being responsible for it after graduation too.

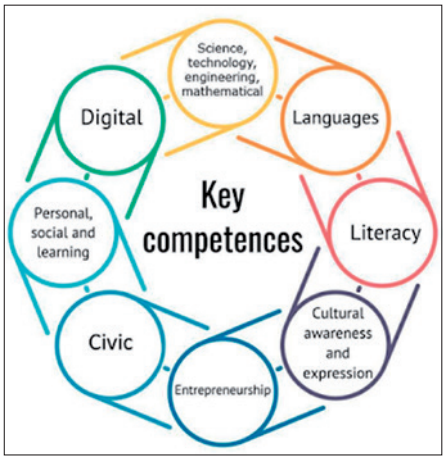

Figure 1: Key competences for lifelong learning [4].

At the competence level, study programmes should focus on the eight key competences for lifelong learning as adopted by the European Parliament in 2018 [4].

Notable in that recommendation is the focus on science, technology, engineering and mathematical competences, combined with digital skills as key competences for all citizens in Europe. The focus on entrepreneurship in combination with the soft skills of personal, social and learning competences is intended to make Europe more competitive. The combination of the "cultural awareness and expression" competence with civic competences should provide all Europeans with a common framework for values, democracy, globalization and multi-culturalism. Finally, literacy and (foreign) languages and culture are important as a means to learn, listen and express ideas.

These eight key competences are fundamental for personal fulfilment and development, employment, social inclusion and active citizenship. They break with two legacy traditions that have burdened formal education worldwide since the 20th century: the dichotomy between the humanities and the sciences, and the dichotomy between pure and applied training [5].

Towards a new role for universities

There has been a constant evolution in the role of higher education. Originally, universities were pure teaching (viz. transmissive) institutions in which professors passed on to the next generation the accumulated knowledge of the previous generations.

Later, professors were encouraged also to do personal research, and to create new knowledge. With the appearance of research universities, all professors were required to be active researchers. This requirement went hand in hand with the development of a number of research degrees (master's and doctorate degrees). Research universities have contributed enormously to the development of the modern world. Many of the things that we take for granted today have been developed at (or in collaboration with) university laboratories. The availability of large numbers of graduates with research degrees has also led to a professionalization of industry and government agencies.

More recently, universities have been encouraged to broaden the I-shaped profiles of their graduates into T-shaped profiles [6].

This change means that students should have a broad base of general supporting knowledge and skills, supplemented with deep knowledge and skills in one or more areas. In the broad base, the student must learn complex problem solving, critical thinking, creativity, people management, coordination with others, emotional intelligence, judgement and decision-making, service orientation, negotiation and cognitive flexibility [7]. These are the competences that set humans apart from computers and robots.

The deep knowledge and skills element must encourage the student to learn how to push forward the state of the art in a subject, and to create new knowledge and to innovate. The harder students are pushed to stretch themselves in the deep elements,

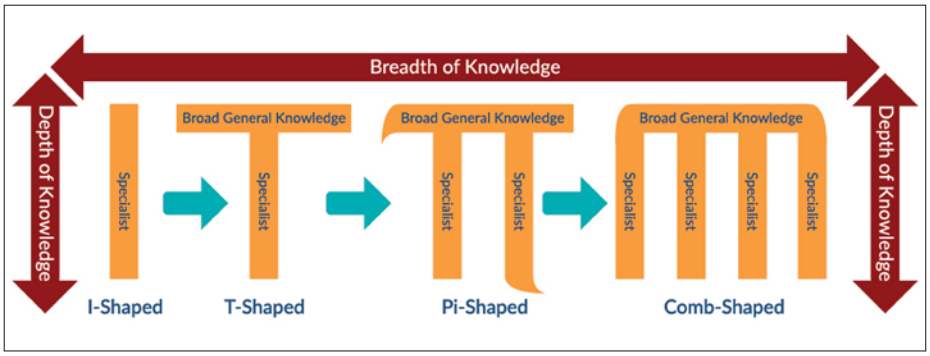

Figure 2: Broadening I-shaped to T-shaped profiles [6].

the more they will learn, and better placed they will be for the challenges of the 21st century. One thing is certain: there is little value in receiving specialist training only to end up doing routine tasks. Such jobs are disappearing because they are the easiest and fastest to automate. T-shaped education offers better guarantees for living well, self-fulfilment and wellbeing.

T-shaped profiles can also help to reduce the shortage of ICT workers in Europe (which is estimated at 1 million). It is not only computing specialists that stand to broaden and update their competences; other disciplines could also broaden their graduates' skill sets by providing them with a basic understanding of computing, big data analytics and artificial intelligence, on a par with the prescribed basics of sciences, history and foreign languages. Such graduates could easily contribute to the ICT sector in roles that are technically less demanding.

There will be a need for a broad range of graduate profiles because society increasingly depends on ICT (for digitizing industry, securing ICT systems, designing smart grids for the transport of renewable energy, development of precision agriculture to reduce the use of pesticides and irrigation, etc.). This measure would also improve the gender balance of the ICT sector in general.

Another recent evolution is that universities are encouraged to actively monetize their research via intellectual property (IP) portfolios and the creation of spin-offs. Most universities now have a technology transfer office tasked with helping researchers to protect their intellectual property and to exploit it, either via an agreement with existing companies, or via the creation of a spin-off company.

In some places, this evolution has led to two additional changes:

- The active promotion of an entrepreneurial mindset in students, via curricular activities that stimulate them to leave their comfort zone, and try to think more like an entrepreneur.
- Becoming an active partner in the regional entrepreneurial ecosystems, supporting and developing them by creating spin-offs and by training the next generation of entrepreneurs through study programmes. This activity also creates attractive jobs for highly specialized graduates (often with PhDs). This job market can slow down the brain drain to other parts of the world, and guarantee that Europe maintains a critical mass of expertise in important sectors.
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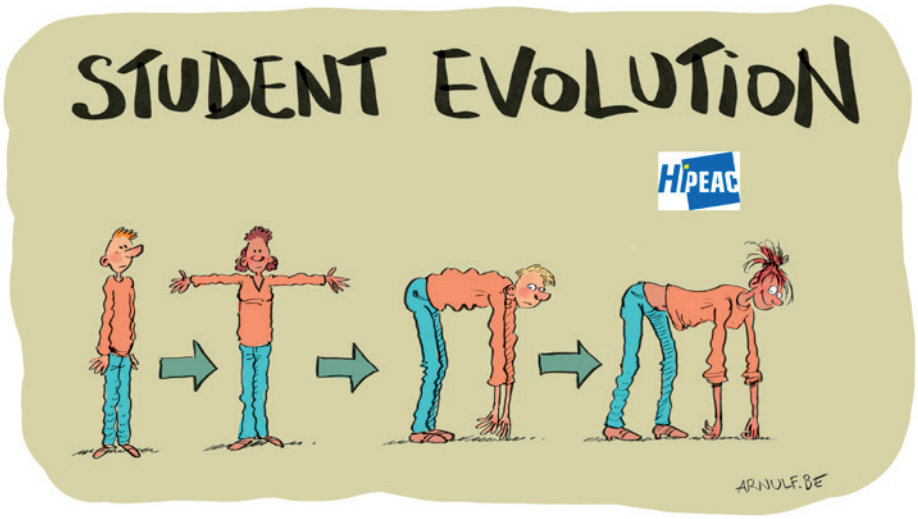
This is a transition through which traditional research universities become entrepreneurial universities that produce not only graduates and research results, but also innovations and economic prosperity. This is the response of higher education to the needs of the post-industrial economy.



The need for digital ethics

In Luciano Floridi's formulation [10], humans have lived through prehistory (where communication was verbal and the clan was the information agent) to history (where all that someone has been able and allowed to write is written down: this is where the state is the information agent), to "hyperhistory" (where machines automatically produce the majority of data and have become the primary information agent).

By acting as an information agent in hyperhistory, ICT does more than actors did in history: it "wraps" the world in a digital envelope designed to facilitate computerized operation within it. We humans are being progressively absorbed into that envelope of which we are less and less in control. A few examples illustrate this situation.

1. The combined effect of exponential increase in processing power and equally exponential decrease in processing cost is the generation of an exponential amount of digital data. Exponential phenomena are problematic: when you begin to notice them, it is because they have become sufficiently large to catch the eye. Yet it then only takes a few more steps for them to ramp to gigantic proportions, entirely beyond control.
   The quantity of data being produced today already vastly exceeds the available storage capacity, and this will only worsen in the future. This means that massive amounts of data should be deleted daily or never even recorded. Deciding what to delete or what to skip is not a merely technical decision if that data is subsequently used to train AI systems, which, increasingly, is tantamount to "writing history", because deletion or skipping may cause harmful bias in the learned inferences.
2. Digitalization has broken the link between place and law. Geographical space and cyberspace do not coincide: the old legislative foundations no longer apply and the spreading of digitized information in cyberspace is very hard to control. Not surprisingly, therefore, some legislators have reacted to this situation by pushing forward the notion of "data sovereignty", which enforces the rights of the state (place) over the data originating within its boundaries. Examples of such efforts are the GDPR and the recently invalidated EU-US Privacy Shield [11]. This move, however, goes counter to the

original fabric of the internet, the web and the logic of their pipelines. Adopting sovereignty-driven norms calls for a rethink of the architecture of the internet and of the web above it.

3. Current ethical frameworks often assume that there are humans, or at least living biological beings, involved in an action. When two computers attack each other with malware, there are no living beings involved in the action, but malicious people are at the origin of the problem. This is why digitalization requires us to reconsider existing ethical frameworks and to adapt them for the various world envelopes that ICT keeps creating. There is a need to develop digital ethics as a discipline (similar to e.g. bio-ethics or medical ethics). The fact that some universities are setting up chairs and institutes in digital ethics is a promising evolution.

We are at a point at which computing engineers who develop hardware and software for decision-making systems should be more acutely aware of how ethics "flows" in their systems, e.g. the fact that a seemingly insignificant decision to store only relevant events in a database and leave others out might eventually lead to a bias in systems that use the database. Unfortunately, however, current computer science (CS) and computer engineering (CE) education scarcely extends to understanding the workings of ethics. We therefore believe it is necessary to include the basics of digital ethics in all higher education study programs, and certainly in computing curricula.

As part of ethics education, it is essential to include quality courses on sustainable computing. Rather than assuming there are no limits other than physical laws, computing education should start with the premise that any solutions should be delivered within the capacity of Planet Earth, from sustainable materials to energy-efficient software. Indeed, Europe could be a leader in the field of sustainable and ethical computing studies.

Incorporating ethics and sustainability into computing education will not be achieved by adding siloed ethics, philosophy or law optional courses within CS and CE curricula. Such courses would risk being isolated and not "germinating" in the students' minds. It is reported [12] that top-quality schools have begun recruiting philosophers in their CS departments and had them contribute to the design the syllabi of curricular courses. This is a promising approach that Europe should explore further.

Conclusion

Education has always been important. Excellent education is key to solving the global challenges of the 21st century. Without a well-trained workforce, Europe will not be able to compete with the rest of the world. Human minds are the most important natural resource that we have in Europe.

Europe was the birthplace of modern education, and it has one of the best education systems in the world: free, often excellent, education for all children up to the age of 18, and affordable higher education. Thanks to its education system, Europe has one of the best-trained and most professional workforces in the world.

An effective education system is also an enabler of social mobility and a prerequisite for sovereignty. It is an asset that we should cherish, protect and make future proof. This requires adapting it to a changing reality and evolving needs, and making it capable of driving future progress instead of undergoing it. It is the only way to stay on top in a knowledge-based global economy and to safeguard European sovereignty.

It is time to develop digital ethics as a separate discipline and to integrate it into computing curricula.

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