Educating People for the Digital Age

The problem

The current world is no longer an environment populated – beyond living entities and inanimate objects – just by physical man-made objects and systems. In current society, aptly called the "digital" society, there is a huge variety and number of "digital systems", devoid of any physical substance, which affect our physical world. Just think of the entire communication and media sphere, where physical letters and messages are now completely dematerialized in the form of e-mails, posts, and tweets (and the digital systems managing them), or of the social network sphere, where digital systems more and more substitute for what once was direct meetings and encounters.

This realm of "digital systems" is driven by scientific laws, as those in the realm of physical machines, **which makes up the science called *Informatics***. It is a rigorous scholarly discipline, with its own distinctive and rich set of concepts, theories, principles and methods (see the Appendix for details), also known as Computer Science or Computing in USA and elsewhere. Its scientific relevance is backed up by about 2 million peer-reviewed articles (out of an estimated overall total of 70 million) published in academic journals throughout the world since its birth around 60 years ago.

Understanding the principles of this science early in school is essential to allow every citizen to have the basic knowledge required to understand, use, participate in, influence, and contribute to the development of the digital world, and to facilitate the harmonious development of a fair, just and safe digital society. This will also have the long term effect of increasing the availability of skilled personnel which every industry sector needs to continue its progress and to fully realize its potential. Given the larger and larger share of the world economy that is affected by these digital systems, **the development of European Union's economic and social prosperity and its ambition to be a world-leading player in the future of our society and planet cannot be properly addressed without an appropriate education of all its citizens in Informatics**. This will also allow them to more safely and critically navigate and contribute to a fast expanding info-sphere consisting more and more of algorithms that may be biased or information that may be flawed or incomplete.

The evidence

A report our coalition "Informatics for All" published in 2017 gathered data on the status of Informatics Education in Europe from 55 administrative units (countries, nations, and regions) of Europe (plus Israel) with autonomous educational system. While the report confirmed that across Europe there is a growing awareness of the importance of offering young students the opportunity of sound education in Informatics, it also showed that in several countries/regions **students could graduate from secondary schools without having ever been exposed even to the basic principles of Informatics**.

The report identified that the provision of Informatics education was quite uneven across Europe: only in 22 out of 50 educational regions was Informatics available to all pupils; in a further 10 regions it was available to just some students; in several noticeable cases, no Informatics teaching was available at all. When students could elect for Informatics there was evidence of poor uptake, often as low as 10%. Moreover, in almost 40% of investigated regions students have a first contact with Informatics as a scientific discipline only in the higher secondary school, and in most of these cases it is offered only as an elective subject. Given the low level of awareness there is in the general public with respect to the scientific nature of Informatics (often considered just as a vocational discipline) very few are the students following them. The consequence is that Europe risks "harming its new generation of citizens, educationally and economically".

On the contrary, in the US the grassroots movement started in 2013 by Code.org first convinced Obama to release the "keep America on the cutting edge" video. Subsequently, the "Every Student Succeeds Act", approved by the Congress in 2015 with bipartisan support, introduced Computer Science (CS) among the "well rounded educational subjects" that need to be taught in schools. In January 2016, President Obama launched the initiative "CS For All" with the goal "*to empower all American students from kindergarten through high school to learn Computer Science and be equipped with the computational thinking skills they need to be creators in the digital economy, not just consumers, and to be active citizens in our technology-driven world*". In September 2017, the White House (under President Trump) issued a directive to the Department of Education to spend at least $200m annually to help teachers in realising this vision. In addition, US industry committed an additional $60m per year for 5 years.

As a result, **policies changed in 49 US states** to establish CS education standards, make CS courses count towards high school graduation, to establish dedicated CS positions in State Education Agencies, etc. Seven years after they started, they are seeing significant results. There is a marked increase in enrolment in CS university courses, meaning their digital job gap is going to be narrower than in Europe. Moreover, the **enrolment from female students and other under-represented groups has doubled, contributing to a more diverse IT workforce**, which is known to be an important factor for successful innovation.

Israel, to cite just one more non-European country, teaches Informatics (as an elective subject) from 4^{th} grade in primary school up to the end of secondary since many years, and their IT industry sector is one of the most advanced one in the world.

In Europe, only in UK there has been something similar, with a Computing Curriculum introduced since school year 2014-15 in all levels of schools and with an ad-hoc Institute for educating teachers to teach informatics founded in 2018 with £80m. In 2019, Denmark started a 3-year long field trial test on Informatics education in primary school and Poland introduced an Informatics curriculum in primary school. In Italy the large grassroots movement "Programma il Futuro" has since 2015 brought 3 million students to study the basic concepts of Informatics and in France the government has introduced in 2018 Informatics teacher certification for middle schools teachers. In all cases, it is too early to see the results, but these facts shows Member States are becoming aware of the importance of actions in this area.

The challenge

In the digital society, with an ever increasing presence and use of digital systems and devices, all people - regardless of their special interests, area of expertise and future profession - need not just to develop "how to" digital skills but to receive a basic education in Informatics as a science.

Our coalition has launched in 2019 the "Rome declaration", an appeal to European national and international institutions to include the principles of Informatics in school curricula at all levels.

Implementation of this strategy entails difficult tasks. In higher education, all other study programmes must address and absorb relevant aspects of Informatics; in secondary as well as primary education, Informatics must be developed both as an individual, compulsory subject and absorbed into all other subjects. **These changes represent a truly grand challenge for all educational systems**.

To see why, imagine a society where mathematics only existed within specialised programmes in dedicated departments in higher education, and where citizens in general only had basic skills in elementary arithmetic. Having understood this situation severely affects its possibility of technological development, such an imaginary society then tackles the challenge of bringing a rich mathematical education down to all levels of its educational system. This is the challenge society is facing for Informatics education.

The core aspect is hence **how to teach Informatics to all**. We understand fairly well how to teach Informatics as a specialised subject in higher education, i.e. to would-be professionals. However, teaching Informatics to all, both as independent subject and integrated in other subjects, calls for a need to rethink in overall terms what to teach (both breadth and depth) and how to teach it.

This is not a trivial task and two – plus one – main challenges exists:

- ***Curriculum***: Define schools curricula that progressively develop appropriate knowledge and skills and accommodates the cognitive development of pupils. Produce effective learning materials supporting the defined curricula.
- ***Teachers***: Appropriately educate teachers at all levels to teach a discipline that, differently from any other discipline taught in schools, most of them have never studied either at school or at university. Support them by providing appropriate scaffolding for them to properly and effectively do their work.

Both challenges are made even more daunting by the time factor. Every other scientific discipline has had decades of years to understand exactly what to teach, how and when to teach it. For Informatics education, we do not have this time and, certainly, the pace of technological development will not make this situation easier in the future. Moreover, the cycle of school education organization will force us to work within a yearly time period. However, this has not to prevent us to base our teaching on experimental evidence (which has to be collected), so as to adopt sound approaches whose effectiveness has been tested on the field. From this requirement, the third challenge arises:

- ***Research***: Test and verify that both teaching methods and content, and teachers' education methods and content, are appropriate for the various levels of education and are sequenced in a way able to engage students. Test and verify that a vast and gender balanced majority of them develop appropriate competences, avoiding the detachment that too often characterizes the studying of math and science in school.

Appendix

As mentioned above, Informatics has its own corpus of concepts, theories, principles, methods, body of knowledge, and open issues, therefore it does not readily fit within the current existing scientific areas, like for example those used for PISA Science Test, namely Physical Systems, Living Systems, Earth and Space Systems.

That is why we are convinced *the science of Digital Systems*, that is **Informatics**, deserve to be added as an additional scientific subject in school since early years. As supporting argument we list below some of its major explanatory ideas, theories and practices:

- **Representation of data** (digital representation for analogic information, approximation of representation, coding systems, data types, compression schema, encryption techniques ...)
- **Data modelling and processing** (formally expressing semantic properties of data; databases; extracting knowledge from data; discovering new relations; learning from new data ...)
- **Human-computer interaction** (interaction; interaction design; usability; participatory design; evaluation; holography ...)
- **Interaction between digital systems and people** (human-to-human communication mediated by machines; interaction with impaired people …)
- **Automata** (automatic mechanisms to execute programs; four fundamental functions: input, output, storage, processing; universal automaton ...)
- **Algorithms** (abstract computation processes acting on data; finite representation of possibly infinite process; “recipe” able to work on any possible input in the given scenario; fundamental techniques: traversing, divide-et-impera, greedy, dynamic programming …)
- **Programs/programming languages** (specification of sets of instructions to be executed by an automa; three fundamental mechanisms: sequence, selection, iteration; hierarchies of programming languages ....)
- **Software architecture and development** (styles and patterns; frameworks; test-driven development; service-oriented architecture ...)
- **Networks** (the internet; the web; web technologies, cloud-based services; mobility ...)
- **Computability** (intrinsic limitations of automata and algorithms; termination; correctness; approximability ...)
- **Complexity** (efficiency of algorithm/ program/ automaton; tractability/intractability; worst/ average/ best case; energy efficient computations ...)
- **Distributed/parallel computation and concurrency** (ways many automata can cooperate to execute a computation; limits and properties; time dependent issues; communication and coordination ...)
- **Quantum Computing (**data representation, programming ...)
- **Security and privacy** (authentication; authorization; integrity; confidentiality; anonymity; ...)
- **AI and machine learning** (“learning” from data; making predictions; ...)
- **Ethics and societal impact** (limits of digital machines, responsibility of their developers; guiding principles, public good, automation ...)