Informatics education:

Europe cannot afford to miss the boat

Report of the joint
Informatics Europe & ACM Europe Working Group
on Informatics Education
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Imagine the dramatic change which could be possible in just a few years... Instead of children bored out of their minds being taught how to use Word and Excel by bored teachers, we could have 11-year-olds able to write simple 2D computer animations… By 16, they could have an understanding of formal logic previously covered only in university courses and be writing their own apps for smartphones.

Michael Gove
UK Education Secretary
11 January 2012
http://bit.ly/w0FNvW

Executive Overview

1. All of Europe’s citizens need to be **educated in both digital literacy and informatics**.
2. **Digital literacy** covers fluency with computer tools and the Internet.
3. **Informatics** covers the science behind information technology. Informatics is a **distinct science**, characterized by its own concepts, methods, body of knowledge and open issues. It has emerged, in a role similar to that of mathematics, as a cross-discipline field underlying today’s scientific, engineering and economic progress.
4. Informatics is a major enabler of **technology innovation**, the principal resource for Europe’s drive to become an **information society**, and the key to **the future of Europe’s economy**.
5. European countries are making **good progress** in including digital literacy in the curriculum. The teaching of this topic should emphasize the **proper use** of information technology resources and cover matters of ethics such as privacy and plagiarism.
6. Informatics education, unlike digital literacy education, is **sorely lacking** in most European countries. The situation has paradoxically worsened since the 70s and 80s.
7. Not offering appropriate informatics education means that **Europe is harming its new generation of citizens**, educationally and economically.
8. Unless Europe takes resolute steps to change that situation, it will turn into a **mere consumer of information technology** and **miss its goal of being a major player**.

Based on an analysis of the current situation and of experiences in many countries, this report makes four key recommendations:

- **Recommendation 1.** *All students should benefit from education in **digital literacy**, starting from an early age and mastering the basic concepts by age 12. Digital literacy education should emphasize not only skills but also the principles and practices of using them effectively and ethically.*
- ***Recommendation 2.*** *All students should benefit from education in **informatics** as an independent scientific subject, studied both for its intrinsic intellectual and educational value and for its applications to other disciplines.*
- **Recommendation 3.** *A large-scale teacher training program should urgently be started. To bootstrap the process in the short term, creative solutions should be developed involving school teachers paired with experts from academia and industry.*
- **Recommendation 4.** *The definition of **informatics curricula** should rely on the considerable body of existing work on the topic and the specific recommendations of the present report (section 4).*

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The context

It is no longer controversial that information-technology (IT) topics should be part of primary and secondary education. The question is: *what* material?

An essential distinction, often lost in public discussions, is between *digital literacy* and *informatics*. Digital literacy (section 1) is a set of basic skills; informatics (section 2) is a scientific subject.

After a careful review of the needs of European society and the current state of education, with particular emphasis on secondary schools, the working group has found that both digital literacy and informatics are essential components of a modern education; failure to recognize these needs is seriously harming the future of Europe.

In particular, without effective informatics teaching, a serious risk exists that Europe becomes a mere *consumer* of technologies designed elsewhere, running on devices also manufactured elsewhere. Such an outcome would have dismal implications for Europe's future. It is the working group's opinion that this outcome is not inevitable and that the key to leadership lies in a modern curriculum integrating informatics as well as digital literacy.

Report scope

This report was developed by a group of experts from academia and industry representing the two principal scientific societies in the field, Informatics Europe and ACM Europe, and covering a broad range of disciplines, experiences and countries. It builds on the considerable body of educational research and experimentation on digital literacy and informatics education developed over the past decades in Europe, the US and elsewhere.

The report defines a blueprint for digital literacy and informatics curricula adapted to the European context, and explains why such curricula are critical to the economic health of European countries.

Developing precise curricula is beyond the scope of the report; it is expected that, based on the report's recommendation, specific curricula will be developed, taking into account the specific constraints of individual countries.

Report structure

This report is organized as follows:

- Section 1 introduces recommendations about the teaching of digital literacy, including not only basic skills but also principles of “safe and effective use” of information technology resources.
- Section 2 describes informatics as an educational discipline and explains its educational value for primary and secondary education, including both its practical role for understanding the IT basis of todays’ societal mechanisms and its intellectual contribution as a scientific discipline emphasizing creativity, constructiveness and precision.
- Section 3 provides an overview of the current state of informatics education in Europe.
- Section 4 presents principles for the teaching of informatics, including references to the considerable body of existing studies and practices as well as the committee’s own recommendation.
- Section 5 discusses the thorny problem of training a cadre of informatics teachers, and shows that short-term solutions are available to bootstrap the process.
- Section 6 summarizes the committee's recommendations for both digital literacy and informatics curriculum topics.

Appendix A is a bibliography, including selected references from the considerable literature on teaching informatics.

Appendix B explains the background behind the present report and the committee that prepared it.

Appendix C presents the two organizations behind this report: ACM Europe and Informatics Europe.

Forthcoming reports, complementing the present one, will describe the state of informatics education in selected European countries, and important on-going initiatives.

> *On 31 January 2013, shortly after the completion of the committee’s work, the UK Education Secretary announced that informatics (computer science) would become a topic in the secondary school exam, the Ebacc, on a par with traditional sciences. It replaces an “ICT Curriculum” focused on digital literacy. We welcome this breakthrough governmental recognition, which gives even more urgency to the implementation throughout Europe of the recommendations of this report.*

1 Digital literacy

Modern society relies at every step on IT. No area of professional or personal life is immune:

- *Communication*: we call each other on a cell phone (a computer system with an antenna), exchange e-mails and instant text messages, check on our friends on social networks, produce and process our photographs and videos digitally.
- *Commerce*: European consumers, like those in the US and other developed economies, increasingly order goods through cryptography-secured Web interfaces.
- *Information access*: searching the web, looking up online encyclopedias, reading online news, tuning in to digital radio and TV, reading e-books have become major activities of everyday life.
- *Content creation*: personal and professional activities rely on text processors, spreadsheets and presentation tools.
- *Enterprise management*: for most companies, the software (accounting, billing, planning…) is the nerve center.
- *Travel, entertainment, product design, logistics*… the list goes on.

In this new “digital world”, information is available almost anywhere at almost any time, computer power is ubiquitous, communication of vast amounts of information is almost instantaneous, and storage capacities seem infinite. But these powerful capabilities only benefit those who have learned to use them effectively.

Any citizen of a modern country needs the skills to use IT and its devices intelligently. These skills, the modern complement to traditional language literacy in language (reading and writing) and basic mathematics, are called **digital literacy**.

Many modern primary and secondary school curricula have started to include digital literacy elements, teaching students to be comfortable with the basic tools of the digital world. The complementary reports describe digital literacy programs in various countries.

Digital literacy should indeed be a required part of the education of all Europeans. Its teaching should start in first grade and students **should be familiar with the basic skills by age 12**.

Digital literacy education, when implemented properly, includes both teaching the technical mastery of digital tools and **the rules for using them effectively, safely and ethically**. Unfortunately, these rules are not always prominently included in existing programs, even though they are essential to ensure that students learn to use digital resources properly. Teaching these topics is also needed to allay the fears of teachers who see the Web as a source of plagiarized homework. Digital literacy education must emphasize not only the “what” but also the “how”, as well as concepts of right and wrong.

The *basic skills* topics include:

- Being able to type.
- Being able to compose and revise documents, presentations and drawings.
- Understanding the fundamental measurement units (size and speed).
- Understanding the basic properties of digital files for text, audio, photos and movies.
- Knowing how to search, copy and store information as digital files.
- Knowing how to organize information by storing files in directories (copy, delete, rename) and to make backups.
- Being able to communicate via various media such as email, social networks and forums.
- Being aware of the currently most suitable software for these activities and able to search for suitable tools.

The *effective, safe and ethical use* topics include:

- Knowing how to behave ethically on the web.
- Being able to distinguish between the real and the virtual.
- Being aware of security and fraud issues
- Being able to exercise caution and to apply a critical mind when dealing with information gathered on the Internet.
- Knowing how to use information found on the Internet properly and ethically for one’s own work; in particular, understanding the difference between legitimate reuse and plagiarism.
- Being familiar with privacy issues; knowing how to respect others’ privacy and to protect one’s own privacy with IT tools.

For both categories of topics, digital literacy courses must adhere to the following rules, in line with principles of educational science:

- The teaching should start at an early age; students should be familiar with the basic concepts by age 12.
- Parents, as well as teachers from all affected disciplines, should be involved at all stages.
- The teaching environment must be safe and secure; children should be protected from dangers such as cyber-bullying.
- The material should include both inter-disciplinary concepts and applications to other disciplines, such as the use of computers in the humanities and in the sciences.
- IT is a fast-evolving area; tools and techniques have a high obsolescence rate. The curriculum should include both mastery of current tools and preparation for technological change.

2 Informatics

Governments and the public all too often satisfy themselves that teaching digital literacy is enough to prepare the citizenry for the "Information Society" that Europe has decided to become. **It is not**. Digital literacy is a practical skill, not a scientific topic or an adequate intellectual preparation for the challenges of a digital world.

For a nation or a group of nations to compete in the race for technology innovation, the general population must in addition to digital literacy understand the basics of the underlying discipline, *informatics*[1]. On the road to an information society, informatics plays the same enabling role as mathematics and physics in previous industrial revolutions.

2.1 The science behind IT

The science behind IT is variously called "*Computer Science*" (the most common term in the US), "*Computing Science*" and "*Informatics*" (the most common in continental Europe). This report uses the last term, taken in a broad sense to cover the entire set of scientific concepts that make information technology possible.

Informatics as a discipline can be said to have originated with a 1936 article by the British scientist Alan Turing, which described a hypothetical computer. Anticipating the field's combination of theory and engineering, Turing went on to design and build (aside from code-breaking cryptographic machines) some of the first actual computers. Since then informatics has developed into a full-

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[11] See [1, 2] for further analysis of the differences between digital literacy and informatics.

fledged discipline, with roots in both mathematics and electrical engineering but many seminal concepts of its own. A list of these concepts would far outgrow the limits of the present report, but here are a few examples:

- **Algorithm**: although this notion goes back to the ancient Greeks, it has taken its full meaning with automatic computers and their ability to carry out billions of operations every second. Algorithms raise major scientific issues: how do we know that an algorithm will *terminate* (a problem that Turing found to be undecidable in the general case, but which needs to be addressed in every specific instance)? How do we know that it is *correct* (implements its specification)? The latter problem is of crucial importance to society, since incorrect algorithms can and do cause havoc, including loss of life. (The 1996 loss of the first Ariane-5 rocket launcher, due to a programming error, was a salutary wakeup call for Europe.) Designing new algorithms is a creative and intellectually challenging activity, which can lead to major innovations.
- **Performance and complexity**: the analysis of algorithms determines how fast they operate. A famous conjecture, "P ≠ NP", asks whether some problems are *inherently* so complex that no efficient algorithms can *ever* be designed to address them. The answer has fundamental applications in many areas, such as the safety of cryptographic protocols. This problem, under investigation by researchers for decades, remains as open today as when it was first formulated.
- **Data structure**: computer programs manipulate large sets of objects, including databases, data warehouses and cloud-based data repositories. They can be not only of enormous size but often also of great structural complexity; the study of how to structure and access data efficiently is an important part of informatics.
- **Concurrency (parallelism) and distribution**: informatics applications involve many processes occurring in parallel, raising issues of synchronization and communication and leading to new ways to reason about the world. The distributed nature of computer networks and the impossibility of synchronizing clocks exactly is a source of challenging conceptual and practical problems.
- **Language**: sophisticated artificial notations such as programming languages play a major role in informatics; using them requires the ability to reason about syntax and semantics, with results that have already had a major impact on other fields such as linguistics.
- **Abstraction**: building and comprehending programs requires a strict separation between "specification" and "implementation", for which informatics has developed far-reaching principles of *information hiding* and *data abstraction*, whose intellectual consequences extend to many other fields of knowledge.

A particular feature of the most ambitious modern software systems is their size and complexity, which arguably exceed those of any other systems built by humankind. Modern operating systems, for example, include over 50 million lines of program code. It is impossible to comprehend such systems and control their evolution without a strict scientific and engineering approach.

2.2 Informatics at the core of modern society

Informatics concepts are at the root of the digital world. To take again a few select examples among many possible ones:

- Google's 35-billion-euro business model largely rests on algorithms such as "Page Rank", a "fixed-point algorithm" that made Web searches practical.
- Trust in e-commerce, a 260-billion-euro industry worldwide and rapidly growing, relies on cryptographic algorithms resulting from decades of R&D; the safety of these transactions is predicated on the above-mentioned P ≠ NP conjecture.
- Cell phones and particular smartphones, a key everyday tool, are computer systems equipped with antennas, internally relying (apart from advances in electrical engineering) on a myriad of sophisticated algorithms and data structures.
- The GPS infrastructure and navigation systems for cars and other vehicles are based on complex informatics systems and algorithms. With Galileo, Europe has already made major strides in this area.
- The music industry has been revolutionized by standards such as MP3 (invented in Europe) and its defining algorithms and data structures.
- Twitter, Facebook and other social networks rely on sophisticated systems written in modern programming languages, some of them originally invented in Europe.
- Weather prediction has turned from guesswork to a reliable discipline thanks to computer models based on ever more refined algorithms and data structures. This success is representative of a deep change in the natural sciences, justifying the current emergence of "*big data*" as a major research area.
- Much of the remarkable growth of India in recent decades has been the result of that country's massive investment in training informatics experts, resulting in a growth, over two decades, from almost nothing to an 80-billion-euros-a-year software industry, no longer just an "outsourcing" proposition but a global IT player competing with the most advanced US and European companies.

For other sciences, informatics often plays the role of a common, multi-disciplinary enabler, similar to the role of mathematics. Informatics-based techniques are essential today for all disciplines, from physics and mechanics to the humanities; even in the arts, informatics is often a key to innovation.

2.3 Informatics as a key educational topic

Over the past century, a key factor in establishing today's industrial society has been to include as compulsory subjects in the secondary school curriculum, with some preparation in primary school, such fundamental scientific disciplines as mathematics, physics, chemistry and biology. It is not that one wants to train every student to become a mathematician, physicist, chemist, or biologist; rather, society has recognized the need for every citizen to understand the basic concepts of these sciences, as there is no technology and no sound economic reasoning without mathematics, no engineering without physics and chemistry, no medicine without biology.

This requirement remains as valid today as it was in the past.

The new factor is the emergence of a new scientific subject, informatics. In today's world, and even more as we move towards an ever more computing-intensive world, being familiar with informatics is as critical to every citizen as being familiar with traditional scientific disciplines. To be prepared for the jobs of the 21st century, students must not only be digitally literate but also understand key concepts of informatics.

The emphasis on informatics as a science as opposed to just using digital technology also helps a proper *gender balance* in the field: the scientific value as well as the emphasis on the human issues (such as understanding users and their needs) is attractive to students of both genders.

2.4 Computational thinking

To capture the distinctive contribution of informatics as a paradigm for looking at the world, Jeannette Wing coined [3] the expression **computational thinking**. Computational thinking is a problem-solving process with distinctive problem-solving techniques and general intellectual practices.

The **problem-solving techniques** include:

- Representing information through *abstractions* such as models and simulations.
- Logically *structuring* and *analyzing* data.
- Automating solutions through *algorithmic thinking*, involving carefully described sequences of steps taken from a well-defined catalog of basic operations.

- Identifying, analyzing and implementing possible solutions with the goal of achieving the most *efficient* and combination of steps and resources, including both human and hardware resources.
- Formulating problems in a way that facilitates the *use a computer* and computerized tools to help solve them.
- *Generalizing* the problem-solving process to a wide variety of problems.

These techniques are of value to all citizens not only for their direct application to dealing with computers, networks, software and tools but as tools for dealing with many different kinds of problems in many disciplines.

The **intellectual practices** include:

- Confidence in dealing with *complexity* (since software systems commonly reach a degree of complexity far beyond what is routinely handled in other forms of engineering).
- *Persistence* in working with difficult problems.
- Tolerance for *ambiguity* (to be reconciled with the necessary rigor in ensuring the correctness of the solutions).
- Ability to deal with *open-ended problems*.
- Ability to deal with a mix of *both human and technical aspects*; the human dimension (user needs, quality user interfaces, appropriate training, user psychology…) is always essential in IT systems.
- Ability to *communicate* and work with others to achieve a common goal or solution.

Here too the benefits extend far beyond the confines of informatics.

2.5 Informatics in the curriculum

The problem-solving techniques and intellectual practices of informatics have a natural place in modern education. As a subject in the curriculum:

- Informatics fosters **creativity**, by illustrating the variety of ways to approach and solve a problem.
- Informatics is **constructive**: designing algorithms is engineering work, producing visible (if virtual) artifacts.
- Informatics helps **master complexity**: learning to solve informatics problems helps solve complex problems in other areas.
- Informatics enhances **accuracy** and precise reasoning: writing successful programs requires exactness in every detail.

These skills are teachable, and must be taught, in the primary and particularly secondary school curriculum. As Barr and Stephenson explain [4]:

> *It is no longer sufficient to wait until students are [at university]*[2] *to introduce these concepts. All of today's students will go on to live a life heavily influenced by computing, and many will work in fields that involve or are influenced by computing. They must begin to work with algorithmic problem solving and computational methods and tools in K-12*[3].

The injunction of "*not waiting until students are at university*" is particularly relevant:

- Not all students go to university. Those who end their education at the secondary level still need to be comfortable with the basic intellectual tools of the information age, the same way they are comfortable with the basic tools of mathematics.
- Many students, whether they go to university or not, get exposed anyway to some IT techniques through non-academic sources; for example they may learn to script games, produce add-ons for social network mechanisms, develop Web sites and services, use spreadsheets with non-trivial computations. Often, they encounter these informatics-related skills in an unstructured, ad-hoc fashion, without any awareness of the underlying principles. It is the role of the educational system to correct these misconceptions, build upon the students' creativity, and weave it in a structured learning process. This goal requires a proper informatics education: scientifically-grounded and adapted to the students' age.
- All university disciplines today require informatics skills. It is essential for the instructors to be able to rely on entering students' knowledge of basic concepts, rather than having to teach them from scratch, which often includes un-teaching unsound ideas gained from ad-hoc learning. (It is typical that an entering university class today includes 20 to 40% of students with some prior programming experience.) The situation here is again similar to that of mathematics, where a basic set of concepts and skills is assumed from entering university students.
- Beyond specific informatics competencies, all university disciplines require analytic skills, for which informatics in primary and secondary schools is an excellent propaedeutic.

This analysis shows that the role of informatics in primary and secondary education, like the role of mathematics, is two-fold: practical and educational.

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[2] For "*at universities*" the cited text uses "*in college*", which in the US context includes universities but also other institutions of tertiary education. For simplicity we stick to the European term.

[3] "*K12*" is US terminology for primary and secondary schools.

Practically, informatics is a necessary skill for European students to get the informatics-intensive jobs of the 21st century. *Educationally*, informatics is an invaluable intellectual tool for developing essential conceptual skills that will serve students through their careers and through all areas of work.

3 The state of informatics education

Given the importance of informatics as the scientific and engineering basis for the information society, and the ubiquitous political discourse about the importance of innovation, high technology and IT, one might expect that informatics education would by now have found its natural place in the curriculum of industrialized countries, particularly in Europe. Unfortunately and paradoxically, this is not the case. In fact, informatics education has retreated in most European curricula since pioneering efforts in the 1970s and 1980s.

In the US, reports by the ACM and the Computer Science Teachers Association (CSTA) [2] showed that while some progress has been made in digital literacy, informatics education lags sorely behind.

Various European countries had introduced successful informatics elements into their curricula starting in the 1970s, but in many cases these efforts have been dropped due to insufficient awareness of the importance of informatics and the frequent misunderstanding that digital awareness is all that needs to be taught. The forthcoming supplementary reports will provide country-by-country descriptions of the state of affairs, based in part on the direct experience of committee members.

The needs, context and history of computing in each country are indeed different, and each should devise its specific curriculum solution. The general requirements and principles are the same, however, and considerable country-independent material is available to help devise national informatics curricula. The next section highlights such material and presents the committee's conclusions on what a successful curriculum should include.

4 Principles for an effective informatics curriculum

The committee performed a comprehensive review of the considerable existing material on building informatics curricula, including among many others the (UK) Royal Society report [7], the CSPrinciples site, Snyder [1, 2], the Computing at Schools Initiative [5], and the work of the CSTA. Two major conclusions follow from that review.

The first is the sheer number of existing experiences demonstrating that **it is indeed possible to teach informatics successfully in primary and secondary education**.

The second conclusion is in the form of *two core principles* for such curricula. Existing experiences use a wide variety of approaches; there is no standard curriculum yet, and it was not part of the Committee's mission to define such a standard informatics curriculum for the whole of Europe. The committee has found, however, that while views diverge on the details, a remarkable consensus exists among experts on the basics of what a school informatics curriculum should (and should not) include. On the basis of that existing work, the Committee has identified two principles: leverage students' creativity, emphasize quality.

4.1 Leverage student creativity

A powerful aid for informatics teaching is the topic's potential for stimulating students' creativity. The barriers to innovation are often lower than in other disciplines; the technical equipment (computers) is ubiquitous and considerably less expensive. Opportunities exist even for a beginner: with proper guidance, a creative student can quickly start writing a program or a Web service, see the results right away, and make them available to numerous other people. Informatics education should draw on this phenomenon and channel the creativity into useful directions, while warning students away from nefarious directions such as destructive "hacking". The example of HFOSS (Humanitarian Free and Open Software Systems) shows the way towards constructive societal contributions based on informatics.

Informatics education must not just dwell on imparting information to students. It must draw attention to aspects of informatics that immediately appeal to young students, to encourage interaction, to bring abstract concepts to life through visualization and animation; a typical application of this idea is the careful use of (non-violent) games.

4.2 Foster quality

Curious students are always going to learn some IT and in particular some programming outside of informatics education through games scripting, Web site development, or adding software components to social networks. Informatics education must emphasize **quality**, in particular software quality, including the need for correctness (proper functioning of software), for good user interfaces, for taking the needs of users into consideration including psychological and social concerns. The role of informatics education here is:

- To convey the distinction between mere "coding" and software development as a constructive activity based on scientific and engineering principles.

- To dispel the wrong image of programming as an activity for “nerds” and emphasize its human, user-centered aspects, a focus that helps attract students of both genders.

5 Breaking the teacher availability deadlock

An obstacle to generalizing informatics education is the lack of teachers. It follows from a chicken-and-egg problem: as long as informatics is not in the curriculum, there is little incentive to educate teachers in the subject; as long as there are no teachers, there is little incentive to introduce the subject.

To bring informatics education to the level that their schools deserve, European countries will have to take both long-term and short-term initiatives:

- Universities, in particular through their informatics departments, must put in place comprehensive programs to train informatics teachers, able to teach digital literacy and informatics under the same intellectual standards as in mathematics, physics and other sciences .

- The current chicken-and-egg situation is not an excuse for deferring the start of urgently needed efforts. Existing experiences conclusively show that it is possible to break the deadlock. For example, a recent New York Times article [6] explains how IT companies such as Microsoft and Google, conscious of the need to improve the state of education, allow some of their most committed engineers and researchers in the US to pair up with high school teachers to teach computational thinking. In Russia, it is common for academics who graduated from the best high schools to go back to these schools, also on a volunteer basis, and help teachers introduce the concepts of modern informatics. All these efforts respect the principle that outsiders must always be paired with current high-school teachers.

Many creative solutions can be devised *today* along these lines.

6 Conclusions and recommendations

It is a matter of grave concern to Informatics Europe and ACM Europe that European nations are **harming their primary and secondary school students**, both educationally and economically, by failing to offer them an education in the fundamentals of informatics.

Continuation of this failure would **put the European economy at risk** by causing students to lag behind those of many other countries, including emerging but increasingly competitive countries (India is the most obvious example but by far not the only one).

Informatics education must become, along with digital literacy, an obligatory part of general education. Appropriate informatics education enhances human capability in the form of both practical skills, essential for success in all human disciplines, and conceptual benefits, in the form of effective ways of reasoning about the world (“computational thinking”). All workforces across Europe will be dependent on future Informatics education to retain our living standards. Informatics will be necessary to future economic health: this is where the next generation is going to be doing the important work and Europe overlooks this at its peril.

The specific recommendations follow from this analysis and the work of the committee. For brevity we have summarized them in *four recommendations*, which have been detailed in the rest of this report:

- **Recommendation 1.** *All students should benefit from education in **digital literacy**, starting from an early age and mastering the basic concepts by age 12. Digital literacy education should emphasize not only skills but also the principles and practices of using them effectively and ethically.*
- ***Recommendation 2.*** *All students should benefit from education in **informatics** as an independent scientific subject, studied both for its intrinsic intellectual and educational value and for its applications to other disciplines.*
- **Recommendation 3.** *A large-scale teacher training program should urgently be started. To bootstrap the process in the short term, creative solutions should be developed involving school teachers paired with experts from academia and industry.*
- **Recommendation 4.** *The definition of* **informatics curricula** *should rely on the considerable body of existing work on the topic and the specific recommendations of the present report (section 4).*

Appendix A: Selected bibliography

[1] Lawrence Snyder: *Being Fluent with Information Technology*, Nat. Acad. Press, 1999 (http://www.nap.edu/openbook.php?record_id=6482&page=1)

[2] Lawrence Snyder: *Bringing Fluency with Information Technology to High School*s, in *CSTA Voice*, Volume 1, issue 3, December 2005, http://bit.ly/cCPUFR.

[3] Jeannette Wing: *Computational Thinking*, in *Communications of the ACM*, vol. 49, no. 3, pages 33 – 35, March 2006

[4] Valerie Barr and Chris Stephenson: *Bringing computational thinking to K-12: what is Involved and what is the role of the computer science education community?*, in *ACM Inroads archive*, vol. 2 no. 1, March 2011, pages 48-54, http://dl.acm.org/citation.cfm?id=1929905.

[5] Jacques Delors: *Learning: the Treasure Within*, Report to UNESCO of the international Commission on Education for the Twenty- first Century, UNESCO publishing, 1996, http://www.unesco.org/delors/.

[6] Nick Kingfield: *Fostering Tech Talent in Schools*, in *New York Times*, 30 September 2012, http://nyti.ms/Sudld4.

[7] (UK) Royal Society report: *Shut Down or Restart? The Way Forward for Computing in UK Schools*, January 2012, http://bit.ly/zDqu7F.

Appendix B: About this report

European IT experts in both academia and industry have long been concerned about the lack of proper informatics education in primary and secondary schools.

In early 2011, Informatics Europe and ACM Europe, as the main organizations representing informatics professionals in Europe, decided to join forces and establish a common working group including some of the top experts in the field, under the leadership of Professor Walter Gander from ETH Zurich. The Boards of the two associations defined the mandate of the working group as follows:

- Use the reach of the membership of both associations to undertake a **review of informatics education** as it exists in schools in Europe.
- As part of this review, perform a **systematic assessment** of what is being taught in computing, in both compulsory and optional nature of curricula.
- Assess whether the current curricula **match Europe's "information society" charter**.
- Provide some **general recommendations** (short of actual curricula) on informatics education in schools in Europe; where relevant, these should help foster the development of more detailed national curricula.

The committee conducted intensive discussions in the following months, both electronically and at two in-person meetings in Barcelona: on 24-25 March 2011 and at the European Computer Science Summit on 20 November 2012. The report went through numerous iterations and benefited from discussions with many experts in the field from both Europe and the rest of the world.

The members of the committee are experts in informatics and education, representing a broad cross-section of disciplines, professional interests, experience and national origins.

Appendix C: About Informatics Europe and ACM Europe

Informatics Europe (http://www.informatics-europe.org) is the association of European informatics/computer science departments and research laboratories. The mission of Informatics Europe is to foster the development of quality research and teaching in informatics. Specific aims include:

- To act as the representative of the European informatics research and education community.
- To foster high-quality research in the field.
- To keep improving the quality of informatics teaching.
- To help the public understand the contribution of informatics to economic development and the scientific challenges of the discipline.
- To foster the cooperation between education, research and industry.
- To establish effective relations between the informatics community and governmental authorities.
- To provide links to other national and international organizations with complementary aims.

Among its many services, Informatics Europe organizes the **annual European Computer Science Summit**, where deans of departments, laboratory directors and senior faculty and researcher gather to discuss common issues; provides **department evaluation** for interested institutions; administers awards such as the **Best Practices in Education Award**.

ACM, (http://www.acm.org), the world's largest educational and scientific computing society, delivers resources that advance computing as a science and a profession. ACM provides the computing field's premier Digital Library and leading-edge publications, conferences, and career resources. The **ACM Europe Council** (http://europe.acm.org/) was launched to recognize and support European ACM members and activities. Comprised of European computer scientists, it aims to increase the level and visibility of ACM activities across Europe. It is focused on a wide range of activities, from high-quality ACM conferences in Europe, to expanding ACM chapters, to encouraging greater participation of Europeans in all dimensions of ACM. Its goals are:

- To join with other computing and scientific organizations in Europe to offer new programs and activities.
- To encourage nominations of European members for the advanced grades of Senior Member, Distinguished Member, and Fellow.
- To increase the number of ACM conferences in Europe.
- To increase chapter activity in Europe.