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Informatics as a Fundamental Discipline for the 21st Century

INFORMATICS FOR ALL is a coalition whose aim is to establish informatics as a fundamental discipline to be taken by all students in school. Informatics should be seen as important as mathematics, the sciences, and the various languages. It should be recognized by all as a truly foundational discipline that plays a significant role in education for the 21st century.

The European scene. In Europe, education is a matter left to the individual states. However, education, competencies, and preparedness of the workforce are all important matters for the European Union (EU).

Importantly, there is a recognition that the education systems of Europe do not collectively prepare students sufficiently well for the challenges of the digital economy. These systems need to be fundamentally transformed and modernized. In January 2018, a Digital Education Action Plan,[1] which set out a number of priorities, was published by the EU. The most relevant priority for our initiative is "Developing relevant digital competences and skills for the digital transformation," and the Plan suggests one way to implement this is to "Bring coding classes to all schools in Europe." This is important, but more is needed, as we will explain in this article.

ACM Europe and Informatics Europe. ACM Europe (europe.acm.org) was established in 2008, and Informatics Europe (www.informatics-europe.org) in 2006. From the early days, the two organizations have collaborated on educational matters; through this liaison, they are seen to project to the wider community a single message about aspects of informatics[a] education. In 2013, the two groups set up and funded a Committee on European Computing Education (CECE) to undertake a study that would capture the state of informatics education across the administrative units of Europe (generally, these units are the countries, but within Germany, for instance, there are 14 different administrative units with autonomy regarding education).

The CECE study paralleled the highly influential U.S. study *Running on Empty*[11] that had drawn attention to the state of computer science education in the U.S. The CECE study gathered data from 55 administrative units (countries, nations, and regions) of Europe (plus Israel) with autonomous educational systems through the use of questionnaires and a wide network of reliable contacts and official sources.

The report on that work was published in 2017.[3] The three themes of informatics, digital literacy, and teacher training provided the framework for the study. Informatics was

a In most of Europe, informatics is synonymous with computing or computer science.

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defined as knowledge and competencies about computational structures, processes, artifacts, and systems. Digital literacy was seen as basic user skills, such as conversancy with standard tools like word processors, Web browsers, spreadsheets, and so on.

While the report confirmed that, across Europe, there was a growing realization of the importance of sound school education in informatics, it also showed a largely variable level of effort and achievement across administrative units. For instance, the report found that informatics was available to all pupils in only 22 out of 50 units, while in a further 10 units it was available to just some students, and in several noticeable cases, no informatics teaching was available at all. When students could elect to take an informatics course, there was evidence of poor uptake, often as low as 10%.

The authors of the CECE report included a number of recommendations that would serve to improve the situation. Those recommendations addressed each of the three areas (informatics, digital literacy, and teacher training), and these form the basis of the Informatics for All initiative.

Informatics for All

The task of moving forward with the CECE recommendations was seen as different in character from the survey work. Importantly, the Informatics for All Coalition was formed by the joint efforts of ACM Europe, Informatics Europe, and the Council of European Professional Informatics Societies.[4] These organizations all share a common concern about the state of informatics education throughout Europe, and are committed to stimulating activity that will lead to significant improvement.

In moving forward, the new organization took the opportunity to present a perspective on informatics education that would reflect the advances that have occurred since 2014, when the CECE work properly began.

Building on the CECE recommendations, the report *Informatics for All: The Strategy*[12] was produced. The emphasis of the report is on informatics education, with informatics seen as the science underpinning the development of the digital world—a distinctive discipline with its own scientific methods, its own ways of thinking, and its own technological developments.

By emphasizing the constructive and creative elements of the discipline, the role of informatics in innovation and discovery and its role in shaping the digital world, the discipline is seen as an essential element of education for the 21st century. Its role in competitiveness and in the economic prosperity of Europe (and beyond) further adds to its vital nature.

The report, which contains eight recommendations (see the accompanying figure), was formally launched in Brussels in March 2018. The launch was attended by representatives of the European Commission as well as representatives of industry and academia; it received uniform, enthusiastic support.

Two-tier strategy. In many ways, the Informatics for All initiative mirrors the CS for All initiative launched in the U.S. in early 2016 (see sidebar). A crucial element of the European approach, which distinguishes it from the CS for All initiative, is the two-tier strategy at all educational levels: Informatics as an area of specialization, that is, a fundamental and independent subject in school; and the integration of informatics with other school subjects, as well as with study programs in higher education. Perhaps overly simplified, the two tiers

The eight recommendations from *Informatics for All: The Strategy*.[12]

Curriculum Considerations

- All students must have access to ongoing education in informatics in the school system. Informatics teaching should start in primary school.
- Informatics curricula should reflect the scientific and constructive nature of the discipline, and be seen as fundamental to 21st century education by all stakeholders (including educators, pupils, and their parents).
- Informatics courses must be compulsory and recognized by each country's educational system as being at least on a par with courses in STEM (Science, Technology, Engineering, and Mathematics) disciplines. In particular, they must attract equivalent credit, for example, for the purposes of university entrance.

Preparing Teachers

- All teachers at all levels should be digitally literate. In particular, trainee teachers should be proficient (via properly assessed courses) in digital literacy and those aspects of informatics that support learning.
- Informatics teachers should have appropriate formal informatics education, teacher training, and certification.
- Higher education institutions, departments of education, as well as departments of informatics should provide pre-service and in-service programs, encouraging students to enter a teaching career related to informatics.
- Ministries should be encouraged to establish national or regional centers facilitating the development of communities of informatics teachers who share their experiences, keep abreast of scientific advances, and undertake ongoing professional development.

Teaching the Teachers

- Intensive research on three different facets, curriculum, teaching methods and tools, and teaching the teachers is needed to successfully introduce informatics into the school system.

The U.S. Initiative CS for All

The CS for All initiative, launched by President Barack Obama on January 30, 2016,[6] was highly imaginative and a catalyst for a burst of initiatives in computer science (CS) education in the U.S. It fired the imagination and provided a focus for great activity centered on the promotion of CS at all stages of education. The financial commitments were impressive, even eye-watering!

The initiative could be seen as the culmination of earlier work on CS education supported by the National Science Foundation (NSF), the CS Principles course launched by the College Board,[7] the extensive work of the Computer Science Teachers Association (CSTA),[8] and efforts by ACM, by code.org, and by many others. Within ACM, the efforts included work on policy matters by the Education Policy Committee, harnessing the invaluable support of major industrial players through Computing in the Core (which has now merged with the code.org Advocacy Coalition), lobbying on Capitol Hill, as well as actions from groups with members in the ACM Education Council.

may be characterized as Learn to Compute (specialization) and Compute to Learn (integration).

All students—regardless of their special interest, area of expertise, and future profession—need to be educated in informatics and apply those knowledge and skills as an integrated competence in all subjects and professions. In so doing, they must ensure that technological development is directed towards the achievement of a better, safer, fairer, and more just society.

The second tier of the strategy, integrating informatics with other disciplines, has huge educational potential.

Through digital models, subjects can be taught in novel and more engaging ways, and data-driven approaches will open doors to new dimensions of understanding and new ways of learning subjects. Similarly, through programming of, say, simulations and games, knowledge and insight in a subject can be expressed in more individual, novel, useful, and creative ways (instead of the traditional reproduction of knowledge in written or oral form).

By integrating informatics in other disciplines, students are provided the advantage of having an additional novel, specific way of thinking to describe and explain phenomena (often referred to as "computational thinking"), complementing that of other scientific disciplines and contributing to their better, more thorough understanding. This is pursued even in STEM, for example, Weintrop,[16] and K–12 SF.[14]

Implementation

The challenge now for the Informatics for All Committee is to bring about change leading to the realization of the strategy. It is highly unlikely that the recommendations will simply be mandated; rather, a carefully considered approach that leads toward the acceptance of the recommendations seems far more realistic.

The implementation problem has to be addressed within each country where responsibility for education resides. Within each country, groups consisting of administrators, academics, teachers, industrialists, employers, and others, could come together and (with sensitivity and caution) create pressure and initiatives that would lead to change as required.

There are different areas of responsibility and different possible activities within these areas:

Education authorities. Administrators have responsibility for the proper recognition of disciplines, and related matters. Accordingly, they have a role in the implementation of certain aspects of the recommendations:

- recognition of informatics as a science,
- the education of teachers of informatics, and
- the education of all teachers.

Curriculum development (includes pupils and parents). Within the CECE report, there are comments that suggest current informatics curricula are not uniformly popular with pupils and their parents. For informatics to be a discipline taken by all, there is a need to review and revise (and in some cases, design) curricula to ensure the discipline is considered an essential one for the 21st century by all stakeholders, including students and their parents.

The motivation of students must be heightened dramatically; all students, including the best students, must see informatics as highly relevant. The curriculum is predominantly technical in nature, and has to capture the essence of the discipline, emphasizing the relevance to people and society in general and to the young in particular, thus including fundamental issues with the practical and more theoretical aspects being carefully interwoven. To motivate students, attention can be drawn to creativity, innovation, and applications, and the massive impact these have on society, particularly highlighting the use of big/deep data, Internet of Things, and developments in machine learning and their impact on the 'future of work.'

Role of higher education. Within higher education institutions (HEI), expertise should be mobilized to support the development of competence and capacity. There are four main aspects:

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- Staff in HEIs can provide expertise and advice to guide developments, such as in advising on relevant curricular standards (detailing what can and should be taught at different stages of school education).
- HEIs often are engaged in the education and training of teachers, and in their professional development. Their forward thinking can serve to continually improve teaching expertise; this can happen at the stage of initial teacher education, and through continuing professional development.
- Within HEIs, research typically features strongly, and the Informatics for All strategy stresses the importance of research. In this context, HEIs might partner with schoolteachers, educationists, and/or others to drive forward relevant research agendas.
- HEIs are a powerful force, perhaps the single most powerful force, in terms of influencing the delivery of the curriculum in schools. What are the requirements for entry to specific programs of study?

Role of professional bodies and the EU. Professional bodies, such as the Council of European Professional Informatics Societies (CEPIS), will typically have strong links with industry and will be in a position to effectively harness industrial perspectives; they typically will be recognized as such by government. It is expected that they will voice strong views about the need for informatics education, especially in relation to the economic development of the country and workforce planning. Where their feelings are particularly strong, they can bring pressure to bear at the governmental level to provide national resources for teacher training, research, and more. They also may be able to provide resources to aid education. It would also be desirable to complement the EU's Digital Action Plan with national initiatives, possibly supported by EC resources.

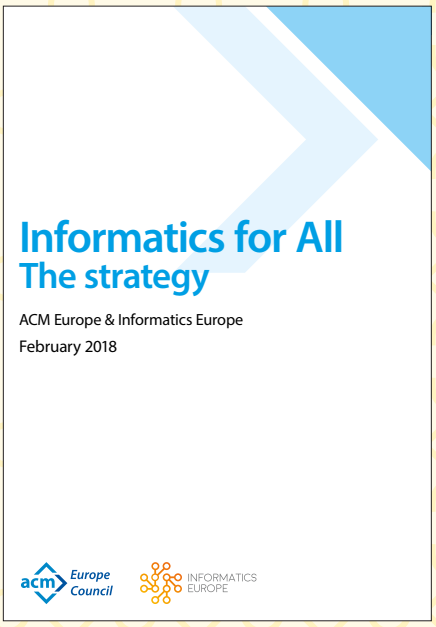
Curriculum issues. Adopting a completely new subject to a national school curriculum is challenging for many reasons. A general but very concrete challenge is how to provide the necessary space in the curricula. We do not believe that the school system of 2019 has reached a fixed point with respect to mandatory subjects; thus, in whichever way possible, space must be found. We feel that each country will have to find her own solution, matching her constraints and situation.

As mentioned, a curriculum should include the foundations of the discipline, including theoretical and implementation aspects. Clearly it should not be just a downgrade of university curricula, but a curriculum should be specially designed for each school level (elementary, middle, and high school). New curricula research should be conducted to examine and find the appropriate methodology and pedagogy to design such curricula for the different levels of school.

Human and Societal Perspectives

Informatics dramatically differs from other sciences in terms of the way it empowers. With informatics, there is powerful support for automating cognitive tasks[15] and this has implications for all domains and professions. Moreover, the related concept of computational thinking is recognized as having relevance more widely.[2,17,18]

In Iversen,[13] the concept of computational empowerment is seen as an important development of computational thinking that places an emphasis on the abilities needed to effectively deploy informatics. Based on a critical analysis of current tech-



nologies, it pulls together technological insights and innovation and links these to the role that informatics plays in the development of personal life and of society. In this way, future generations will have the knowledge and skills from informatics to become competent, constructive, and critical co-creators of the digital future.

In a context where informatics education begins early in primary school and is carried forward through to the later years of high school, there is the opportunity to develop thoughts about the possible wider relevance of ideas from informatics, and to develop them in a meaningful way that places emphasis on the human (and societal) benefits and implications. Just making suggestions about possible improvements opens the door to considerations about (software-inspired) innovation, and more.

It is important that students acknowledge software as creator and bearer of values and culture—that these aspects are explicitly or implicitly embedded in the software. Software is formed through design processes that include critical decision-making; students must learn to creatively develop software, and learn to analyze and understand the impacts of software and digital artifacts in general. For example, these visions for a strong human and societal perspective are thoroughly embedded in the newly designed Danish curriculum for informatics in school.[9]

Augmented intelligence. The concept of augmented intelligence relates to the effective use of informatics in augmenting human intelligence. The discussion above regarding STEM was one instance of that though even there, there is scope for extending that further.

Developments in language translation, voice recognition and simulation, and related advances fueled by developments in machine learning suggest great scope for reshaping the curriculum in many disciplines.

The role of ethics. Those who develop software ought to do so in a responsible manner, ensuring that 'bad things' do not happen. The related issues tend to be captured in a code of conduct that provides guidance on good practice. In the past, such codes have tended to stress matters such as 'do not cause harm'. While this remains important, a more enlightened approach places an emphasis on contributing positively to the benefit of a fair, just, and secure society through the use of computers and computing. The recent ACM Code of Ethics and Professional Conduct[5] takes such a view.

The role of teachers. Teachers are the key to the success of the implementation of any study program and the introduction of any new curriculum or technologies. A good supply of well-educated and enthusiastic teachers is crucial to support every discipline in schools at all levels, but the lack of suitable teachers at all levels also forms a bottleneck for the successful implementation of Informatics for All. Thus, efforts should be devoted to recruitment, and to establishing a supportive informatics teacher community.

Concluding Remarks

The primary focus of Informatics for All is to stimulate the recognition that informatics is a vital, important discipline, both as a subject of study on its own, and also integrated with other disciplines with many of the ideas having relevance more broadly.

The two-tier approach facilitates the integration of informatics into the teaching of other disciplines, reshaping the curriculum for all disciplines and generally providing a basis for making education systems truly relevant for the 21st century. It also opens up many avenues for research; for instance, about how to teach disciplines effectively in a world of constant change.

Given that digital technology is taking an increasingly relevant and pervasive role, providing to all citizens an appropriate level of informatics education is necessary to ensure balanced development of the digital society.

Informatics for All is a catalyst for important thoughts for reforming the wider educational systems to the benefit of students and employers, and ultimately the economy of Europe.

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