Informatics for All
The strategy

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Contents

Executive Summary

Informatics for All is an initiative devised jointly by ACM Europe and Informatics Europe. Its purpose is to give due recognition to Informatics as an essential foundational discipline for education in the twenty-first century. Informatics is the science underpinning the development of the digital world, and it is having a profound effect on all aspects of modern society. The discipline has fundamental conceptual and practical facets. The considerable economic impact of its technological developments, as well as its role in empowering research and development across all sectors, has created an imperative to address educational issues.

The initiative is based on the long-term recommendations of the report *"Informatics Education in Europe: Are We All In The Same Boat?"* which presented the state of relevant education, and related teacher training, across Europe. Its conclusions highlighted the serious need for an initiative to ensure that Informatics is properly recognised within the educational systems so that Europe is well placed to compete globally in reaping the benefits that flow from Informatics.

This paper highlights the need for a two-tier strategy for Informatics education at all levels. First and foremost, the first tier takes the form of Informatics as a specialisation, i.e. a fundamental and independent school subject. The second tier would be the integration of Informatics with other school subjects. To achieve this goal, in both tiers research is needed to address what and how to teach (curriculum, methods and tools), and how to educate teachers.

To address this grand challenge **important recommendations** on Informatics are provided in Section 3.2, on Teacher issues in Section 4.2. and on Research in Section 5.3.

1. Introduction

The digital society that has developed over the past 20-30 years (with the personal computer, the internet, and the world-wide web) was only the beginning of a new era. Dramatic changes now challenge and impact all professions, disciplines, and school subjects.

Informatics is the science underpinning this development, a rigorous scholarly discipline distinct from, but on an equal footing with, other disciplines. Through its scientific methods and technological developments, Informatics has brought about transformational changes across a range of sectors, and it plays a vital role in many aspects of current research, innovation and development. It is important to pave the way to the future, properly educating the current and future generations of students and citizens.

This paper argues the importance for Europe of widespread Informatics education. This is based on the essential role Informatics plays in the development of Europe's economic prosperity and highlights the fact that the increasing shortage of skilled personnel is creating difficulties in the industry and impeding Europe's ability to fully realise its potential for innovation. Informatics education initiatives have flourished worldwide, where generally the term used is "computer science". Europe has to recognize the importance an appropriate Informatics education has to enable its competitiveness.

An initiative, Informatics for All (described below), has been launched to take forward and further develop the recommendations that had appeared in the report of the Committee on European Computing Education which described the status up to 2016 of Informatics education in Europe. In doing so, the opportunity has been taken to present a more updated perspective and strategy on Informatics education.

1.1 The Committee on European Computing Education (CECE)

Informatics Europe and the ACM Europe Council set up and funded in 2013 a Committee on European Computing Education (CECE) to undertake a study that would capture the state of Informatics education across the countries of Europe. This was seen to parallel the highly influential US study *"Running on Empty"* [1]. It gathered data from 55 administrative units (countries, nations, and regions) of Europe (plus Israel) with autonomous educational systems, using questionnaires and a wide network of reliable contacts and official sources.

A report on that work was published in 2017, with an unprecedented level of detail and information[2]. 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 a highly variable level of effort and achievement across countries and education autonomous regions.

In particular, the report showed that in several countries/regions, students can graduate from secondary schools without having ever been exposed even to the basic principles of Informatics. On the basis of this and other findings, the first and foremost recommendation was that *all students must have access to ongoing education in Informatics in the school system. Informatics teaching should start in primary school.*

1. *Running on Empty: the Failure to Teach K-12 Computer Science in the Digital Age*, published by ACM and CSTA, 2010
2. J. Vahrenhold, E. Nardelli, C. Pereira, G. Berry, M. E. Caspersen, J. Gal-Ezer, M. Kölling, A. McGettrick, and M. Westermeier. 2017. *Informatics Education in Europe: Are We All In The Same Boat?* Association for Computing Machinery / Informatics Europe, New York, NY. https://doi.org/10.1145/3106077. (2017)

The CECE 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%.

1.2 Case Studies

1.2.1 Initiatives in the US

In the US, the "Every Student Succeeds Act", approved by the Congress in 2015 with bipartisan support, introduced Computer Science among the "well rounded educational subjects" that need to be taught in schools "*with the purpose of providing all students access to an enriched curriculum and educational experience*". In January 2016 President Obama launched the initiative "CS For All" whose goal was "*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 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 $60 m per year for 5 years.

1.2.2 Initiatives in the UK

The UK Royal Society published in January 2012 a widely known report (*Shut down or restart? The way forward for computing in UK schools*) arguing that it was essential for all school pupils to gain some familiarity with the science underlying digital systems. It called for the recognition of the great importance to the future careers of many pupils of teaching computer science in schools. On this basis, the English Department of Education published in September 2013 statutory guidance for a national curriculum in England on computing; this term was to include both computer science and computer systems as well as their responsible usage.

The Royal Society then surveyed in November 2017 the status of computing education in the UK calling for a "*swift and coordinated action by governments, industry, and no-profit organizations … [to avoid] … damaging both the education of future generations and UK economic prosperity*"[3]. In fact, while it was noted with satisfaction that all students from age 5 to 14 had regular weekly hours of computing lessons, it was also noted that a majority of teachers were unfamiliar with the subject they taught and did not have adequate support. The report called for "*unhindered access to a structured and ongoing programme of professional development* … [which] … *must support teachers in all schools across the country*".

This situation is particularly relevant since it shows that having a curriculum in place is a necessary but not sufficient condition to ensure reaching the goal of widespread and effective informatics education; teacher preparation is also essential.

3 The Royal Society. *After The Reboot: Computing Education in UK Schools*, Nov. 2017. ISBN 978-1-78252-297-3.

2. Informatics for All

2.1 Initiative Statement

Today's world is digital. Informatics, as the science underpinning the development of the digital world, has brought about the radical and transformational development of professions, scientific disciplines, and social life. As a distinct scientific discipline Informatics is characterised by its own concepts, methods and body of knowledge.

The purpose of the Informatics for All initiative is to establish Informatics as an essential discipline for all, a subject available at all levels throughout the educational system. The vision is that learning Informatics will enable all students to understand, participate in, influence and contribute to the development of the digital world in general; simultaneously, it will provide a significantly improved opportunity for recruiting and educating the large number of IT specialists Europe needs to maintain and improve its position in the digital world economy.

In addition to its importance in its own right, Informatics is essential to education in all areas in the twenty-first century. It supports research, innovation and development across all sectors and provides radical and enhanced opportunities for the teaching of all disciplines, and for education in general. It is important to take advantage of this, even with children of an early age. As a consequence, all students and teachers have to be not only digitally literate, but also educated in fundamental aspects of Informatics.

Moreover, it is important that all citizens receive an appropriate level of Informatics education, enabling them to actively participate in the digital society in an informed way and to more safely and critically navigate and contribute to a fast expanding infosphere consisting more and more of algorithms that may be biased or information that may be flawed or incomplete.

The Informatics for All initiative is based on the long-term recommendations of the report "Informatics Education in Europe: Are We All In The Same Boat?" which presents the state of relevant education, and related teacher training, across Europe. Its conclusions highlight the serious need for an initiative such as Informatics for All.

2.2 Two-tier strategy at all educational levels

In the industrial era, competencies in reading, writing and mathematics were identified as fundamental and necessary skills needed by all in order to learn, act and excel at any subject in school and to participate in a profession in society. In the digital era, these three fundamental competencies must be supplemented by Informatics.

With its capacity to precisely describe how information can be automatically managed and processed, Informatics provides cognitive insights and a useful common language for all subjects and professions. The educational role and position of Informatics must reflect this societal importance.

Informatics education is not just about educating more specialists who can develop and design the ever-increasing digital world and who can accommodate industry's needs and maintain productivity, innovation and growth. First and foremost, it is important to ensure that technological development is directed towards the achievement of a better, safer, fairer and just society.

More specifically, all people—regardless of their special interests, area of expertise and future profession—need to be educated in Informatics and apply the knowledge and skills as an integrated competence in all subjects and professional contexts.

This suggests a two-tier strategy for Informatics education at all educational levels: as a **specialisation**, i.e. a fundamental and independent subject in school and in study programmes in higher education; and as the **integration** of Informatics with other school subjects and study programmes. For both approaches well-educated and skilled teachers are a vital requirement.

2.2.1 Specialisation

In higher education, Informatics programmes have existed for fifty years or more, but the scientific discipline had emerged already in the 1930s—long before the invention of digital computers. The role of Informatics in society and the general perspective on Informatics have changed dramatically since those early days.

Earlier, the field and technology were perceived by others "just" as a useful tool and infrastructure to facilitate numerical, administrative and industrial processes. However, there is an increasing realisation that computers are ubiquitous and drive innovation and development in all fields, that they can exhibit increasing levels of "intelligent" behaviour and that Informatics has to become a fundamental school subject.

Informatics is not only a science in itself; it can be said to constitute a new approach and method in all scientific domains where it offers its own specific way of thinking to describe and explain phenomena (sometimes referred to as "computational thinking"), complementing that of other scientific disciplines and contributing to their better and more thorough understanding.

In this respect it dramatically differs from advances by other sciences in terms of the way it empowers. With Informatics there is not just an improvement in physical actions but a powerful support for automating cognitive tasks. With Informatics there is "knowledge in action" wherever and whenever it is needed without necessarily the constant interaction with human beings (and if/how this can be a menace or a blessing is a highly debated topic).

Thus Informatics represents a radical and unique development in the history of mankind. To fully embrace and exploit its potential, it is imperative to **introduce Informatics as a specialised and independent subject in school** from the early years onwards.

2.2.2 Integration

Just as with professions and scientific fields, all school subjects are gradually transformed because of Informatics. 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 radical 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).

Therefore, all school subjects can benefit from embracing Informatics, and students' competences in Informatics in general and programming in particular will enable radical new ways of learning and expression for any discipline.

To this purpose, it is imperative to **integrate Informatics into the teaching of all school subject**.

2.3 A Grand Educational Challenge

To summarise from the above sections: Informatics programmes have existed as educational programmes in higher education for more than fifty years, but the time has come to expand Informatics to be a subject at all educational levels: primary, secondary and higher education. At all levels, a two-tier strategy is needed with both specialisation and integration of Informatics.

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 also absorbed into all other subjects. These changes represent a truly grand challenge for all educational systems.

Standing back, imagine a situation 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. This would be excessively constraining and would deny the richness that flows from exporting mathematics, absorbing it into the entire educational system as a subject and properly integrating relevant aspects into other subjects.

This is the challenge society is facing in Informatics education. It can be handled, and it must be handled, but it requires a huge and ambitious effort and a humble attitude. The opportunity has to be taken to iteratively experiment and evaluate in order to identify and settle on appropriate ways of implementing Informatics for All.

The core aspect is to rethink **how to teach Informatics to all**. It is fairly well understood how to teach Informatics as a specialised subject in higher education, i.e. to would-be professionals. But teaching Informatics to all, both as an 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 is depicted in Figure 1. Here the expertise in the specialization is seen to flow down to high school and primary school levels and also across becoming integrated with other disciplines at all educational levels.

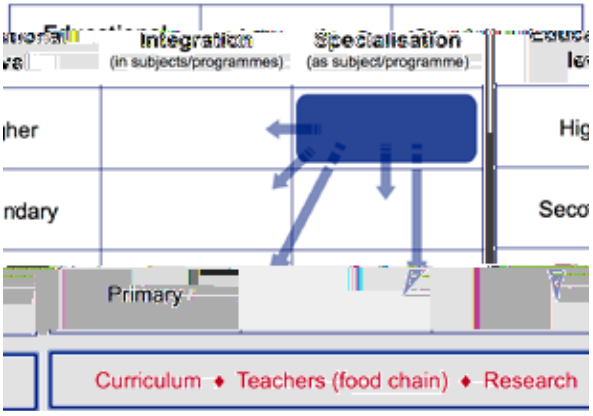

Figure 1: The grand educational challenge

The three specific challenges for both tiers are:

Curriculum: Develop fine-grained schools curricula that progressively develop appropriate knowledge and skills and accommodates the cognitive development of pupils. There is a need to develop effective learning materials that support the curricula.

Teachers (food chain): Appropriately educate teachers at all levels and to support them by providing appropriate scaffolding for them to properly and effectively do their work.

Research: To implement Informatics for All, research is needed to understand exactly what to teach, how to teach it and when to teach it.

These challenges will be discussed in more depth in the next three sections.

3. Curriculum Matters

3.1 Findings from CECE report

The CECE 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 cases no Informatics teaching was available at all. When students could elect Informatics, there was evidence of poor uptake, often as low as 10%.

These observations resulted in a number of recommendations on Informatics. But in addressing these, the Informatics for All committee has taken the opportunity to present a perspective on Informatics that reflects advances that have occurred since 2014 when the CECE work began.

3.2 Curriculum considerations

Each country / region will define its own Informatics curriculum, perhaps addressing national needs and national priorities. These courses need to be attractive, viewed by all (in particular pupils, their parents and teachers, educators, employers) as being of vital and fundamental importance; indeed steps should be taken to ensure that courses have this form of support.

The vast majority of any Informatics curriculum will be scientific in nature, focus on the key concepts in the field and reflect the **constructive** aspect of the discipline. Attention should be given to a range of topics such as data, programming, algorithms, networks and the web, design and human computer interaction, security, privacy and ethical considerations. Moreover, the conceptual and practical elements should be blended in a way that reflects the multiple links between the two. The opportunity might be taken to highlight the role of Informatics in **innovation and creativity** and in bringing about massive transformational change. Informatics also underpins the ongoing development and evolution of the digi-

tal world. There is a societal duty to ensure that this is safe and secure, trustworthy and reliable. To reflect these observations, it should not be possible for a pupil to finish the "mandatory school period" without a sustained period of education in Informatics.

Recommendations

- 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 twenty-first century education by all stakeholders (including educators, pupils and their parents)
- Informatics courses must be compulsory and recognised 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, e.g. for the purposes of university entrance.

3.3 Comments on Digital Literacy

An important driver for education in Digital Literacy is the ability to support learning (across all subjects) as well as to communicate and to be creative. The CECE report found that Digital Literacy was introduced at primary school level in some 79% of the educational areas surveyed. But it also revealed the fact that teacher training in Digital Literacy rarely follows an agreed curriculum.

It is of vital importance that pupils learn to use computers in a disciplined, safe and secure manner that is both effective and efficient. Over and above acquiring digital skills, there is a need to develop the digital capacity and literacy of pupils so that they are prepared for the changing requirements of society and the labour markets of the future. Moreover pupils need to become aware of the potential to evaluate digital products and to recognise their potential for society.

The CECE report drew attention to the fact that Digital Literacy had to be taught from the early stages of education with students being proficient in the basic aspects by the time they reached secondary level; this included providing strong encouragement for pupils to keep up-to-date with relevant technological advances.

Moreover, all citizens must become digitally literate, since many (if not all) of the social and professional services they are using or involved with are today online activities. This requires ongoing teaching of Digital Literacy to the entire population. The professional societies have an important role here.

4. Teachers

The teaching of Informatics should be undertaken only by teachers who have obtained an education and a qualification in Informatics as well as appropriate subject-specific methodological and pedagogical training.

4.1 Availability of teachers

Teachers are the key to the success of the implementation of any study, 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. While scientists mainly research a particular area, and industry professionals work on the development their organization is interested in, teachers should have a broad knowledge of the discipline they are teaching and be able to convey it properly to their students.

Both the CECE report and the Royal Society report highlight the fact that in many cases an undersupply of Informatics teachers is a major concern. Finding skilled and enthusiastic Informatics teachers is especially difficult, since many educated and trained graduates prefer industry where wages are much higher. Currently there seems to exist a challenge: if we want to expose as soon as possible all school students to Informatics, we first need to recruit and educate excellent Informatics teachers.

4.2 Preparing teachers

The recruiting of Informatics teachers must follow standards similar to other disciplines. In particular neither formal requirements nor methodological training should be sacrificed. Difficulties in recruiting teachers to address the demand for Informatics education produce a temptation to reduce standards in the informatics teaching profession. But such moves are short-sighted and in the end damaging to Informatics itself. The challenge of a shortage of Informatics teachers needs to be broken by hiring teachers even in times of budget shortages.

Subject knowledge and pedagogical context knowledge are vital to every subject and especially to informatics which in addition to being the youngest among the sciences introduced in schools, it requires two different kinds of skills and knowledge, theoretical and practical.

Ideally, teachers certified to teach Informatics should major in Informatics and participate in an Informatics certification programme where pedagogical courses are introduced and context pedagogical knowledge is acquired. For the time being, it is expected that governments, e.g. through their Ministries of Education, might provide programmes for existing teachers of other scientific disciplines to assist them to easily move from teaching one discipline to another. Such in-service courses should contain a core of subject knowledge and some content as well as subject-specific methodological and pedagogical courses. Currently two different groups need to be taken care of:

- Veteran teachers with little or no Informatics experience;
- Experienced individuals coming from industry with an Informatics background.

Higher education institutions have an important role in teacher training, e.g. in providing Informatics certification programmes, and on-the-job continuous training. In particular, they might be encouraged to offer Masters courses (both full-time and/or part-time) to open up routes for entry into Informatics education.

The need for support networks for teachers at regional, national and international levels as well as the need for cooperation between the various countries, via conferences, for example, must be recognised. Establishing teachers' centres can assist

in avoiding the Informatics teacher "loneliness" via online forums, sharing workshops, teaching materials, experiences etc...

A similar approach should be followed for teachers of other subjects, teaching Informatics as an integrated subject. The following recommendations hold for teachers operating in both tiers of Informatics education.

Recommendations

- 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 preservice and in-service programmes, 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.

5. Research

The goal of Informatics education research is three fold, to help in designing an updated interesting and challenging **curriculum**, to find effective **teaching methods and tools** for all school levels, and to find more effective ways of **teaching the teachers**, i.e. the pedagogical content knowledge.

Since informatics education is a relatively new discipline, research can benefit from building on the experience of other scientific disciplines and from international cooperation, while paying attention to cultural and national aspects. This cooperation is especially necessary where small countries are involved.

5.1 Curriculum

Research should be carried out so as to produce adequate curricula for the different schools levels: primary, lower secondary and upper secondary. It has to be done iteratively by designing, implementing, testing and refining both materials for students and guides for teachers.

Research should involve researchers in Informatics education, both in Universities and in schools, and also school teachers so as to base proposals and experimentations on the actual school context.

5.2 Teaching methods and tools

It is most important to find effective teaching methods for the different school levels, and explore the use of methods that will support the teaching and learning processes, assisting teachers in their endeavours, like for example the use of augmented intelligence (i.e. the ability of computers to exhibit increased forms of "intelligent" behaviour) in educational environments.

Although ongoing research of Informatics education has taken place for many years, most of it refers to high education / college or high school; there is still not enough evidence as to how to teach the subject effectively at all levels in schools. Further re-

search is required to address the issues, particularly in primary and lower secondary school.

Research of effective teaching methods has shown that high quality teaching can have an impact on students' choice of the subject in school and later on recruiting for the subject in higher education; this is very important in times when we try to engage more students in the Informatics disciplines and later in industries.

5.3 Teaching the teachers

What should a proper well-established teacher preparation programme include? What tools should teachers be given to properly convey the disciplinary knowledge and skills to their students? What is the pedagogical content knowledge? Is different teacher training for different levels of school needed? These and other questions should be explored. Some research referring to these questions has been published, but there is scope for cooperative activity building on research findings of other scientific disciplines and exploiting cooperation with disciplines such as Education and Learning Sciences.

Recommendations

- 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.

6. Towards Implementation

In order to progress the strategy, the ACM Europe Council and Informatics Europe have approached CEPIS (the Council of European Professional Informatics Societies). CEPIS has a special interest group studying how the national computer societies can assist in the teaching of computing in schools This group provided valuable input to the final drafts of the document and is supportive of the strategy. As a consequence, the Informatics for All Coalition has been established and CEPIS has joined as the initial partner and will commit its member societies to provide support at national level. It is envisaged that this will be most important in the implementation of the strategy.

The task of implementation will fall to each country and to the relevant educational authorities. In many case there are likely to be policy and resource implications, e.g. to address issues with respect to teachers and their ongoing professional development.

The CECE report has revealed that there is great variation across Europe in the development of Informatics education. Some countries are well advanced and others less so. Thus, the time taken to address the implementation of these recommendations will vary, but for all they should be seen as important targets to reach.

Within each country there will be experts from ACM Europe, from Informatics Europe, from professional societies, from industry, etc. who can come together to provide advice on the way ahead.

An important task for the Informatics for All committee is to gain widespread support for this strategy statement from groups who are influential and who can assist with implementation.

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