Informatics Education for School— A European Initiative

By Michael Caspersen, *It-vest networking universities and Aarhus University, Denmark*, Judith Gal-Ezer, *Open University of Israel, Israel*, Andrew McGettrick, *Strathclyde University, Glasgow, UK* and Enrico Nardelli, *Tor Vergata University of Rome, Italy*

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In the age of the digital revolution, informatics must be developed as a fundamental discipline in school. But what steps can be taken to support the advancement of informatics education at school level across Europe, especially when responsibility for education is devolved to each individual country (and sometimes to regions within countries)? To provide a coherent vision and shared terminology, we have recently proposed an informatics reference framework for school. This article provides some background and an overview of the framework.

INTRODUCTION

In the current digital society, people use digital devices and systems each day for many purposes. One could say that there isn't a single area of services, production, or communication that does not employ, in some form or another, digital applications. It is now widely recognised that any person, whatever their field of activity, should be digitally skilled. The education systems must respond appropriately.

The development of these applications is driven by the scientific laws of the discipline of informatics. Concepts like data, algorithms, computing machines, programming, design, ethics, and social implications must to be part of the standard school curriculum. Just as pupils learn about the living and the physical world in the natural sciences in school, all pupils should learn informatics in school so that they can flourish in the digital world.

The digital society requires a basic education involving these principles, accompanied with practical work to experiment and experience the subject matter and to develop skills in computational analysis and expression. Moreover, since digital technology is affecting human society, it is necessary for all students to be aware of the implications that technology, developed based on informatics principles, can have on human beings and society. Informatics has also a focus on creative, innovative, and ethical applications of computing technology.

The "Informatics for All" coalition (see next section) has been working for many years towards the goal of having the principles of informatics included as part of school curricula at all levels in all European schools. During this activity, there has been fruitful interaction with the European Commission that has recognized the importance of informatics. Indeed, the Digital Education Action Plan 2021-2027 explicitly states [5, p.13]:

> Computing education in schools allows young people to gain a sound understanding of the digital world. Introducing pupils to computing from an early age, through innovative and motivating approaches to teaching, in both formal and non-formal settings, can help develop skills in problem-solving, creativity and collaboration. It can also foster interest in STEM-related studies and future careers while tackling gender stereotypes. Actions to promote high quality and inclusive computing education can also impact positively on the number of girls pursuing IT-related studies in higher education and, further on, working in the digital sector or digital jobs in other economic sectors.

It includes as action 10 **"a focus on inclusive high-quality computing education (informatics) at all levels of education"** [5, p.15], and in the accompanying Staff Working Document [6, p.4] it states:

> Informatics education in school allows young people to gain a critical and hands-on understanding of the digital world. If taught from the early stages, it can complement

digital literacy interventions. **The benefits are societal** (young people should be creators not just passive users of technology), **economic** (digital skills are needed in sectors of the economy to drive growth and innovation) **and pedagogical** (computing, informatics and technology education are vehicles for learning not just technical skills but key skills such as critical thinking, problem solving, collaboration and creativity).

It therefore appears likely that all countries of the European Union will be proceeding—just as the UK has already done—to insert informatics as an essential discipline for mandatory education.

In this paper, and even though education (and so curricula, etc.) is a matter where responsibility is devolved to individual countries (and in some cases regions), actions and guidance whose purpose is to make this goal possible are identified.

INFORMATICS FOR ALL

Today's world requires the introduction of informatics into the school system as a distinct scientific discipline with its own characteristics, concepts, methods, and body of knowledge. The report "Informatics Education in Europe: Are We All in the Same Boat?" [4] described the state of informatics education, digital literacy education, and related teacher training in Europe at the time of that report (2017). Its conclusions highlighted the serious need for an initiative to address inadequacies, and to bring about the implementation of the report's recommendations.

This motivated the ACM Europe Council, CEPIS (the Council for European Professional Informatics Societies), and Informatics Europe to form the Informatics for All coalition. The three organisations and their network spread widely into various European communities and beyond, providing a broad coverage and support from the various European Communities. The International Federation for Information Processing (IFIP) became involved subsequently. (See sidebar for their descriptions.)

Much of the background to Informatics for All is contained in [2]. It captures the coalition's 2-tier strategy, specifically that

- informatics must be seen as a stand-alone fundamental scientific discipline to be studied by all students from an early age, and
- informatics should be integrated into the teaching of all other disciplines leading to deeper forms of education in these other disciplines.

More recently the coalition issued the Rome Declaration. It starts as follows[1]:

We, the members of the "Informatics for All" coalition

- Considering that early knowledge of scientific principles is necessary to prepare citizens to be able to take informed decisions about their future
- Considering that society is becoming increasingly digital
- Considering that the discipline known as Informatics (or Computer Science) is the scientific core of the digital society, shapes the digital world, and explains how it works and evolves

CALL upon all European national and international institutions

To exercise their moral suasion power so that the principles of Informatics are included as part of school curricula at all levels.

[1] The full text of the Rome Declaration can be seen at [10]. The declaration has now been translated into 12 languages and, as of May 2022, there have been 272 signatories.

The ACM Europe Council is composed of individual European computer scientists. Informatics Europe represents the public and private research community of informatics in Europe and neighbouring countries, bringing together university departments, research laboratories and industry. CEPIS is the representative body of national informatics associations throughout greater Europe. IFIP, founded under the auspices of UNESCO, as a federation for societies working in information processing.

THE EUROPEAN INFORMATICS REFERENCE FRAMEWORK FOR SCHOOL

Given that, on the one hand, education is an issue that at the level of the European Union remains the responsibility of the individual member states, and, on the other hand, there is a great variety of languages, cultures, and school systems in the European continent, we have set ourselves the goal of defining not a curriculum for the teaching of informatics that is valid for all European schools, but a higher level reference framework that provides a shared vision of the discipline while allowing each country to implement its own curriculum in a manner compatible with its history and tradition. "Unity in diversity" has been our motto …

The framework was submitted for review by national informatics communities and subsequently edited according to feedback from the communities covering a total of 14 European countries. The final version of the *Informatics Reference Framework for School* was published in English in February 2022 and will be translated into several languages [8].

Specific attention has been paid to stimulate curriculum designers towards the themes of inclusion, diversity, and gender to ensure that informatics education is made accessible, enjoyable, and empowering for all.

Defining a minimal set of high-level requirements to which the various national curricula should adhere seemed to be the right goal to allow each state to define its own specific approach, while coordinating the different national paths towards the common goal of being able to better compete in the global market of the digital society.

To this end, the framework is intentionally concise and flexible. It lists only five competency goals that all students should achieve at the end of their compulsory schooling, paying attention also to the social aspects of digital technologies, a topic whose relevance is becoming more and more important (see Figure 1 for a condensed version of the overall aims and objectives and [8] for the complete exposition).

At the end of upper secondary education, pupils will:

1. **Use** digital tools in a conscious, responsible, confident, competent, and creative way.
2. **Understand** the principles and practices of informatics and their multifaceted applications.
3. **Analyse, design, frame and solve** problems "informatically."
4. **Creatively develop** computational models to **investigate and communicate** about phenomena and systems.
5. **Identify and discuss** ethical and social issues associated with computational systems and their use, potential benefits, and risks.

Figure 1: Overall aims and objectives.

THE FRAMEWORK

The framework is conceived as a "high-level map" of informatics that identifies a list of 11 core topics each characterised by a brief description.

The 11 core topic areas identify the essential *principles, practices and implications* of informatics and information technology and include a substantial focus on the human/societal aspect and the responsibility and empowerment of informatics.

The framework is designed to be robust to the inevitable evolution of the discipline (see Table 1).

INDICATORS OF OUTCOMES

In an annex to the framework document, there is a list of a limited number of examples of indicators of outcomes, and this is supplied for each topic area of the reference framework (Table 1). They are not intended to be prescriptive and are provided for illustrative purposes only, to show examples of the initial steps of the evolution of the framework in a more articulated curriculum and to stimulate thinking and action for curricula designers. Specific countries will take their own path to defining their own curricula according to requirements and constraints of their specific school system.

For illustration, we provide an example of *indicators of outcomes* for the core topic area *responsibility and empowerment* (see sidebar on the next page).

Table 1: Core topic areas and brief descriptions

Core topic areas	Description
Data and information	Understand how data are collected, organised, analyzed, and used to model, represent, and visualize information about real-world artefacts and scenarios.
Algorithms	Evaluate, specify, develop, and understand algorithms.
Programming	Use programming languages to express oneself computationally by developing, testing, and debugging digital artefacts; and understand what a programming language is.
Computing systems	Understand what a computing system is, how its constituent parts function together as a whole, and its limitations.
Networks and communication	Understand how networks enable computing systems to share information via interfaces and protocols, and how networks may introduce risks.
Human-computer interaction	Evaluate, specify, develop, and understand interaction between people and computing artefacts.
Design and development	Plan and create computing artefacts considering stakeholders' viewpoints and critically evaluating alternatives and their outcomes.
Digital creativity	Explore and use digital tools to develop and maintain computing artefacts, also using a range of media.
Modelling and simulation	Evaluate, modify, design, develop, and understand models and simulations of natural and artificial phenomena and their evolution.
Privacy, safety, and security	Understand risks when using digital technology, and how to protect individuals and systems.
Responsibility and empowerment	Critically and constructively analyze concrete computing artefacts as well as advanced and potentially controversial techniques and applications of informatics, particularly from an ethical and social perspective.

Example of Indicators of Outcomes for Responsibility and Empowerment

Primary: Explain benefits and dangers of using the Internet.

Identify and describe ethical principles to adopt in the use of digital tools.

Lower Secondary: Explain, giving examples, the benefits but also the dangers of social networks. Identify socially and ethically acceptable ways of using digital tools.

Critically reflect on digital artefacts' implications for personal and common practice in concrete situations.

Upper: Explain, giving examples, ethically acceptable uses (e.g., copyright and plagiarism) of information found on the Internet.

Analyse and characterise relations between purpose, intentionality, and opportunities of use of digital artefacts as well as their impact on individuals, communities and society.

SPECIAL SUBJECTS

The decision to aim for a temporally robust framework results in a concise form where the 11 core topic areas are briefly described using generic and invariant terms.

To complement the concise exposition of the framework and to illustrate the richness and relevance of the topic areas, an elaborate contemporary interpretation of all eleven core topic areas is provided. In this exposition, a total of ten special subjects are identified within the core topic areas; these are described in greater detail in a forthcoming supplementary document.

For example, *computing systems* is associated with the description *"Understand what a computing system is, how its constituent parts function together as a whole, and its limitations"*.

The contemporary interpretation of *computing systems* is considerably more elaborate and includes two special subjects, *artificial intelligence*, and *machine learning*. The complete contemporary interpretation of *computing systems* is as follows [8, pp.7–8].

Computing systems. Computing systems exist as an essential component in many devices—mobile and smartphones, robots, pacemakers for the heart, health monitors, aeroplane construction and operation, autonomous vehicles, etc. They importantly support service and production. The requirements on such systems vary greatly, and impact all aspects of the systems, including their hardware and software, their connectivity, their reliability, the safety and security they provide, and whether the systems exhibit "intelligent" behaviour. This topic should provide an opportunity for pupils to explore a range of computing systems and to identify the impact of the application of requirements on its structure and functionality.

A newer and powerful version of computing systems is based on ***artificial intelligence*** (AI), a broad field whose study cuts across many of the core topics of informatics and which has been part of the discipline since the 1950s. Due to its recent rapid developments, driven by machine learning and facilitated by the huge quantities of data now available, it is now seen as a fundamental topic with the potential to fuel economic and other developments. Moreover, the field of AI is also rife with philosophical issues—for example, how far should AI be developed (if at all), whether AI should be restricted in its application areas, how can decisions made by complex AI systems be made explainable. It is therefore important for pupils to understand concepts and various approaches to the development of AI, to draw comparisons between AI and human intelligence, and to recognise applications of AI in the real-world including advantages, limitations, and implications for society.

Experiments with simple AI applications incorporating ***machine learning*** (ML) could facilitate such understanding. ML techniques enable computing systems to adjust their behaviour because of their interaction with the surrounding environment, and, for example, they have obtained well-publicised results within game-playing. They have progressed to enable computers to rival humans' ability at even more challenging, ambiguous, and highly skilled tasks with profound "real world" applications, such as recognizing images, understanding speech, and analyzing X-rays. Today, such machine learning-based computing systems can reliably perform activities that previously were done (and doable) only by humans. They can therefore be used to both augment human decision making and, in some cases, replace it with fully autonomous systems, the latter requiring particular attention to their technical, ethical, legal, economic, societal, and educational consequences.

DISCUSSION AND FUTURE TRENDS

In one sense the publication of the Informatics Reference Framework for School and the subsequent recognition by the EU can be seen as the successful culmination of much debate and discussion about informatics education at all levels in school with this involving many partners across Europe. But in another sense, it must be seen as the start of a new phase.

Firstly, promotion of the document is a key undertaking. Following translation into several key European languages, this can be achieved through the agencies of the members of the coalition. The targets include all interested with a role in informatics education including policy makers, teachers, parents, and guardians as well as pupils of all ages. Important also are key players from business / industry who can be able to influence policy due to their perceptions about future business/industry needs.

In support of these endeavours, the Coalition has produced one additional document and is working on a second one.

In terms of directly engaging the informatics education community, the focus must be on policy makers, especially those in a position to shape change in national (and regional) curricula.

The first document provides guidance and suggestions on how the Informatics Reference Framework for School may be used to create detailed curricula for informatics education [9].

The second document will provide additional details and open for scrutiny and possible inclusion in curricula around ten topics that are just mentioned very briefly in the main Informatics Reference Framework for School. These topics are to recognise and support the great diversity in informatics curricula across Europe.

In terms of directly engaging the informatics education community, the focus must be on policy makers, especially those in a position to shape change in national (and regional) curricula. It is anticipated that such engagement will provide feedback on how best to further support informatics education at school level across Europe.

However, without a cadre of excellent teachers who are well educated in informatics including the associated pedagogy, implementation of the framework, or any study program whatsoever, is deeply challenging. Some regional teacher communities already exist and run yearly or bi-yearly meetings. The coalition will endeavour to extend this initiative to other countries. The coalition intends to hold meetings and workshops to learn from experienced teacher educators, trying to provide general guidelines for pre-service and in-service informatics teacher training programs. Quoting Sandy Lenning, a teacher at Denali Elementary: "If anything is going to happen, teachers have to make it happen." [1]

The views expressed above have been reinforced in the recent report [7]. Eurydice is a network of national education systems, which is part of the European Education and Culture Executive Agency in the Directorate General for Education, Youth, Sport, and Culture in the European Commission. ❖

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Michael Caspersen
Managing director of It-vest-networking universities and honorary professor at Aarhus University, Aarhus, Denmark
mec@it-vest.dk

Judith Gal-Ezer
Professor emerita of the Open University of Israel, Ra'anana, Israel
galezer@openu.ac.il

Andrew McGettrick
Professor emeritus in the Computer and Information Sciences Department at Strathclyde University, Glasgow, UK
andrew.mcgettrick@strath.ac.uk

Enrico Nardelli
Professor of informatics at Tor Vergata University of Rome, Italy and president of Informatics Europe,
nardelli@mat.uniroma2.it

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