Informatics Reference Framework for School

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Executive Summary

The contribution that informatics has made since the last century has fuelled innovative and significant technological advances and vice versa. It makes fundamental contributions to current economic, educational, industrial and social development.

Informatics importantly has the capacity to support and augment human reasoning and potential. Education systems have a responsibility to recognise this and to ensure that young people are equipped to be able to drive forward, judge innovation and take part in the development of a just and fair society.

To properly embrace this development by society in general, informatics has to be seen as an essential aspect of the education of all pupils. The present report, which outlines an informatics reference framework for all young people, bears that in mind. It is intended to offer high-level guidance that may be used by, and indeed stimulate, curriculum designers to review their focus and approach to the subject of informatics.

Following the introductory sections, the heart of the reference framework is described in section 4. A set of aims and objectives for informatics education for all young people is provided in section 4.2 followed by a set of core concepts and an accompanying brief description of these in Table 1 of section 4.3; this conveys a robust structure and a general architecture, which captures an essential view of informatics as a discipline in general education. To complement the general architecture, a contemporary and outward facing view of informatics is offered in section 4.4; this includes discussion of modern developments that relate to topics such as data science and artificial intelligence, as well as attention to related ethical concerns.

Annex A.1 presents a brief description of informatics as a discipline. Annex A.2 presents a limited number of examples of how *high-level* learning outcomes could be described in a concrete curriculum at three levels that reflect indicators of outcomes after primary, lower secondary and upper secondary education.

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1. Preamble

Across major global regions of the world, recent advances in informatics[1] have been recognised for their potential in supporting and driving forward future economic development and industrial growth. Enormous sums of money are being allocated to underpin advances across a range of industries, and ambitious initiatives have been taken in some countries to ensure compulsory informatics education *for all*.[2]

In Europe, there has been similar excitement about the advances in informatics, with these being seen to support areas such as enhanced decision-making, improvements in health care, advances in smart farming, developments in climate change, improved security, as well as increased automation.

Within Europe, a lot of effort has focused on digital competences[3], which mostly address the operational aspects of an appropriate preparation for the digital society; however, education in informatics is still fragmented and receiving insufficient attention.

In its earlier work, the *Informatics for All* coalition[4] developed a *two-tier strategy*[5] for informatics in general education. On the one hand, informatics should be seen as an important foundational discipline with a standing being on a par with mathematics and the languages. But the strategy also highlights the potential of informatics to be integrated in the teaching of all other disciplines, leading to deeper forms of education and insight in these other disciplines.

The *Informatics for All* coalition is presenting this report to address the first tier by providing support for the advancement and development of informatics as a fundamental discipline for the 21st century[6] and to serve as a general reference framework for both tiers.

The *Informatics for All* coalition acknowledges the valuable review feedback received from representatives of the European informatics community to an earlier version of this document.

[1] In some countries, informatics is named computing, computing science or computer science.

[2] See (White House 2016).

[3] The Digital Competence Framework for Citizens

[4] informaticsforall.org

[5] See (Caspersen et al. 2018, pp. 5-6).

[6] See (Caspersen et al. 2019, pp. 60-61).

2. Informatics and Society

The world is becoming more and more “digital”, with pervasive information systems realised as networks of people and technologies interacting in increasingly sophisticated ways in all aspects of life. For example, the development of the Internet, the World Wide Web and accompanying search engines and web services, coupled with the development of the mobile devices for many, provides realms of information and services that can be obtained anywhere at any time.

Informatics is the scientific discipline[7] that underpins the digital world. Given its pervasiveness, it is essential to all disciplines and professions and has increasing importance as a school subject. 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.

Informatics brings understanding to processes of modelling and manipulating real-world objects as well as their digital counterparts. The new way of thinking about problems and their solutions is of key importance for understanding our contemporary and future society, but informatics has limitations and dangers to be aware of (e.g., autonomous systems with possibly unexplainable behaviour and algorithms manipulating public opinion on social networks).

Digital technology differs from all other technologies that humankind has invented. Other technologies enhance physical abilities, but informatics technology (also) enhances our cognitive abilities by supporting and even replacing cognitive tasks and processes with automation, e.g., diagnostic software in health care, driverless cars and autonomous robots. Thus, informatics represents a radical and fundamental novelty, which calls for pertinent education of future generations.

The digital world increasingly impacts the conduct of lives in leisure time, during education and at work; indeed, it has changed where and how these activities are undertaken. Informatics in general, and the particular development of artificial intelligence (AI), underpinned by machine learning and data science, is changing human knowledge, perception and reality – and, in so doing, changing the course of human history. Informatics has made it possible to automate an extraordinary range of tasks, and has done so by enabling machines to play a role – an increasingly decisive role – in drawing conclusions from data and then taking action. The growing transfer of judgment from human beings to machines denotes the revolutionary aspect of informatics and brings new concerns.

It is now considered important that future generations become equipped not just with operational skills (digital literacy), but with the knowledge, understanding and skills of informatics bringing new ways of thinking about and tackling problems in both the real world and its digital counterpart. As a result of the empowerment brought about by education in informatics and with guided attention to their social responsibilities, pupils will be attuned to identify opportunities for improvement and innovation, and will be equipped to embark on such activity. This is needed to bring about change, to contribute to the development of the

[7] See Annex A.1 for a brief description of the discipline of informatics.

digital environment and to ensure the evolution of a safe, secure, environmentally conscious and just society.

In this respect, we are aligned with the **European Commission**, which considers informatics education in school to be of the utmost importance. The Digital Education Action Plan 2021-2027 explicitly states:[8]

> "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[9] **"a focus on inclusive high-quality computing education (informatics) at all levels of education"**, and in the accompanying document, states:[10]

> "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 is a vehicle for learning not just technical skills but key skills such as critical thinking, problem solving, collaboration and creativity)."

Inclusion, diversity and gender remain important issues in informatics education. Inclusive education is a fundamental principle, diversity is a feature of inclusion and gender concern is an issue of diversity.

There is now general acceptance that informatics education must be made accessible, enjoyable and empowering for all. Pedagogical approaches have been developed that encourage and motivate a diverse range of pupils and many new resources have been created to support inclusive informatics education. For example, collaborative learning and physical computing have been shown to support a diverse range of pupils in engaging with informatics. The gender issue is a particular concern in informatics; engagement with informatics at an early age can promote self-efficacy and tackle gender stereotyping before prevailing views become entrenched. Compulsory informatics education counteracts a tendency for girls to opt out and puts the onus on curriculum developers and teachers to create a curriculum that engages girls as well as boys.

With this report, and related initiatives by the *Informatics for All* coalition, we hope to support the advancement and development of compulsory informatics education for all, particularly from primary through upper secondary education.

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[8] See (DEAP 2020a, p. 13).

[9] See (DEAP 2020a, p. 15).

[10] See (DEAP 2020b, p. 47).

3. A Common Informatics Reference Framework

Recognising that within Europe education is a devolved matter, this document outlines a common informatics reference framework that can support the design of school curricula in informatics across Europe. The document is intended to inspire and facilitate curriculum designers across Europe. The aim is to stimulate discussion and debate about informatics education at all levels of school education.

This can be seen as the beginning of a longer conversation; we want to engage further with policymakers, curriculum designers, informatics specialists and practitioners across Europe to inform next steps in designing and implementing informatics curricula.

We advocate that informatics should exist as a discipline at all stages of the school curriculum, starting early in primary school and continuing to exist and develop through upper secondary school. Moreover, we suggest that education in informatics should be compulsory for all pupils from primary through secondary education, having a status and standing similar to that of language and mathematics. Well-educated teachers and teacher-teachers are essential to realise this vision.

This **informatics reference framework** represents the core for the design of an ideal informatics curriculum, but by no means presents a curriculum in its totality. The core is conceived as a set of core topic areas with their associated practices in informatics that all pupils are expected to be competent in by the end of upper secondary education.[11]

In presenting the informatics reference framework, the *Informatics for All* coalition is aiming to support the European school informatics education community in responding to current needs. Our intention is to help those involved in curriculum design to devise informatics curricula that support all pupils in general education (approximately from 6 to 18 years of age) and are attractive and appealing to them through all stages of their school education.

The document is deliberately synthetic and short, to provide a minimum set of high-level common requirements, leaving space for the national communities of colleagues in various countries to derive fully-fledged curricula both attuned to their culture and needs, and coherent with a common European vision of informatics.

Specific curricula will have to be defined in each country, taking into account their traditions, language, culture, and particular synergy with developing basic digital competences and the use of informatics in other subjects. However, we are convinced it is valuable to provide a common reference of understanding that is shared across Europe.

This should be seen as a high-level document that serves as a general reference framework for the implementation of the two-tier strategy for informatics in general education.

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[11] Countries use a variety of structures for describing phases of education. We use the International Standard Classification of Education (ISCED) to define school phases. ISCED level 1 is denoted “Primary education”, level 2 “Lower secondary education” and level 3 “Upper secondary education”. The combination of the three, we denote "General education".

4. The Informatics Reference Framework

4.1 Introduction to the informatics reference framework

We present a foundation that is enduring and can be used flexibly to support curriculum design in different education systems and for different types of schools.

Our reference framework provides key features that enable curriculum designers to create specific curricula to meet their needs.

It consists of aims and objectives, core topic areas and suggested outcomes and is deliberately presented succinctly using generic and invariant terms, in order to possess temporal robustness and to make room for local priorities during its instantiation. It starts with a description of overall aims and objectives – what any concrete informatics curriculum should be seeking to achieve for pupils by the end of upper secondary education.

4.2 Aims and objectives

We are increasingly surrounded by digital artefacts, digital technology and an abundance of data. It is essential that pupils develop knowledge and skills that enable them to competently use existing digital artefacts as well as synthesise data and digital technology for personal and societal needs.

For this to be realised, pupils must gain insight into aspects of informatics broadly in society and acquire insights into significant applications of informatics including their social impact and their relevance to the future of work and life in general, thus fuelling an interest in novel applications, including those in support of other disciplines. At the same time, pupils must develop creative practical skills that initiate, complement and strengthen these insights, particularly with a focus on the impact their products could cause.

The overall purpose of informatics education in school is expressed here as a set of five overall aims and objectives.

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 phenomena, concepts, principles and practices of informatics and the multifaceted ways of applying them to model, interpret, and operate on reality.
3. Analyse, design, frame and solve problems by devising representations, designing algorithmic solutions and implementing these in a programming language.
4. Develop computational models to creatively investigate, understand and communicate about natural and artificial phenomena and systems.
5. Identify, analyse and discuss ethical and social issues associated with computational systems and their use as well as their potential benefits and risks.

Figure 1: Overall aims and objectives

4.3 Core topics

In this section, we provide a high level and robust set of core topic areas that provide a framework for specifying in curricula the concepts, principles and practices of informatics. These topic areas are all related to the aims and objectives listed above, and should be cross-referenced with that list when developing concrete curricula.

The core topic areas are deliberately presented in concise form using generic and invariant terms. This supports temporal robustness and accommodation of local priorities when using the framework to design specific curricula. Proposed names are evocative more than prescriptive, and specific curricula might adopt different terms more suited to a national situation. The set of core topic areas is presented in Table 1.

Table 1: Core topic areas and brief descriptions

Core topic areas	**Description**
Data and information	Understand how data are collected, organised, analysed and used to model, represent and visualise 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 taking into account 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 analyse concrete computing artefacts as well as advanced and potentially controversial techniques and applications of informatics, particularly from an ethical and social perspective.

The list of core topics should by no means be conceived as a guideline for organising teaching and learning material, but merely as a way of structuring the framework.

4.4 Contemporary context and implications

To illustrate the richness and relevance of the topic areas, we develop in this section a discussion on how those core topic areas might be interpreted and expanded in a contemporary context. Compulsory informatics education should not only prepare pupils for the present and the future, but also provide a fascinating and useful insight into the connections of informatics to other subjects.

Data and information. Data about individuals as well as data about the world now form a routine part of life and can influence how people live. Data can take various forms including text, multimedia (sound, video, etc.) and sensor data. Digital devices can be used to collect data on a wide variety of topics (possibly over time). It is important to ensure the quality of collected data; often they should be carefully guarded and used with caution. Collection and use of personal data about individuals should always respect human rights. The analysis of well-targeted data, whether just visualising them using such mechanisms as charts or graphs or using them to provide virtual reality scenarios, can yield new insights or sometimes improved performances in areas such as business or the medical field. Important developments have been made recently in utilising vast amounts of data ("big data") to fuel advances in machine learning, artificial intelligence and robotics. Generally, there are important ethical and legal issues associated with the collection and use of data. With certain forms of data, security, privacy and confidentiality become prime concerns.

The availability of huge quantities of digital data and the increased computational power of tools and systems for their analysis offers the opportunity for ***data science*** to feature in interdisciplinary education across many school subjects. There are various matters that typically have to be considered: what data should be selected for collection; what units should be employed in measuring the quantity and frequency of their collection; what kind of processing is to be employed; who makes decisions about the kind of analysis to be performed. To ensure the quality of the overall process, these important questions go hand in hand to allow students to develop a "data mindfulness" that will become increasingly important in the future to help development and progress of society.

Algorithms and programming. The combination of the concepts of programming, algorithms and ***programming languages*** supports software development. This topic is about the creation of computational structures – eventually sequences of instructions – that can be executed on computers. This is an essentially creative activity that, with an appropriate appeal to design and human-computer interface concepts, underlies the development of all software that runs on the computers of today. The activity also facilitates the realisation of new ideas and new possibilities that can lead to innovation.

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”[12] 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: e.g., 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 as a result 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: recognising images, understanding speech, and analysing X-rays. Today, such machine learning based computing systems are able to 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.

Networks and communication. The Internet enables searching for information in diverse forms, across many facilities through the use of search engines. It provides access to the World Wide Web that holds vast amounts of information, including those in multimedia and hypertext formats. Networks enable computing systems to communicate with one another. These networks may be private and located within one organisation. However, they may also be public, academic, governmental, etc. A very important aspect of networks and communication concerns cybersecurity. Pupils can learn about related ethical issues but also about simple ways of protecting messages, many of these stemming from a historical perspective on code breaking. Additionally, social media provide an important set of communication channels, which can support online learning, for instance.

Human-computer interaction. The interface between the computer and the user is crucial in determining the usability of systems. Different forms of usage give rise to different requirements: for instance, use for display purposes, use for entertainment including games, involvement in in-group sessions via video conferencing systems, and use for learning and education. A particular set of issues arise in considering interfaces for users with special needs or disabilities, such as colour blindness, deafness, etc. Generally, in determining an

[12] By “intelligent”, we mean behaviour that would be considered intelligent if exhibited by human beings.

optimal approach, a disciplined approach to testing is required, and this involves a carefully chosen set of metrics associated with evaluating the experience and effectiveness of the human-computer interface.

An increasingly important application area, both for social relations and entertainment, and subject to very rapid technology-driven changes, is ***computer graphics*****,** the term commonly used to describe the computer generation and manipulation of images. Its uses include cartoons, film special effects, video games, medical imaging, engineering, as well as scientific, information, and knowledge visualisation. There has been a recent boom in ***virtual reality*** personal devices, where users are immersed in highly realistic 3D computer-generated scenarios, sometimes even with haptic feedback; ***augmented reality*** possibilities are related and offer support in many areas, e.g., healthcare. This makes them areas of great interest for school education, at least at the level of awareness of technical possibilities and social impacts, and also due to its connections with mathematics, physics and other sciences.

Design, development and digital creativity. This topic concerns the ability to use computing in creative, liberating ways. Software is formed through design processes that include critical decision-making; pupils should learn how to creatively develop software, taking stakeholders' viewpoints into account, and should learn how to analyse and understand the impacts of software and digital artefacts in general.

Modelling and simulation. Computational modelling is an ideal way of gaining insight into phenomena and dynamic systems in a domain (e.g., natural, social, economic, technical or cultural systems). They also offer ways to explore designs and alternative solutions to problems. More generally, informatics literacy and modelling have the potential to become drivers for renewal and innovation of other educational disciplines.

Simulators play an important role in allowing training or exploration in situations that are, for instance, dangerous or exceedingly expensive, e.g., flight or space simulators. Important developments in this field involve the creation of "intelligent" systems. Even from an early stage of informatics education, pupils can use simulators in a variety of contexts to support their learning.

This topic also provides an opportunity to place an emphasis on the importance of abstraction, being aware of its advantages but also being aware of limitations of (computational) models.

Privacy, safety and security. The protection of individuals' data in the context of both professional and personal life is a topic strictly intertwined with that of ensuring the security of organisations and individuals. It is of huge importance in contemporary society where most data are now in digital form and where more and more interactions are mediated by digital devices. Discussing how to obtain a balance between the two offers one more opportunity to discuss how informatics can provide effective tools and techniques to support confidentiality, integrity and availability of social relations.

Also, focusing the attention of children, even from their early years, on certain ethical issues and on the protection of the digital counterpart of their physical being is of the utmost importance to raise their awareness in a difficult area.

Education has an important role to play in assisting with understanding the risks associated with the management of digital data and systems and how use and behaviour policies can help in mitigating them and to ensure a better safety and the well-being of people and organisations.

Responsibility and empowerment. Exploring a number of applications that have had significant impact socially (and in terms of altering behaviour or social patterns) provides an opportunity for discussion about ethical concerns. The latter have been identified within widely accepted codes of ethics (such as those developed by ACM[13] or IFIP[14]). Questions about social concerns and impact can be further addressed by highlighting development of "intelligent" systems. Developments such as the use of intelligent personal assistants, the increasing role of robotics, and the emergence of autonomous vehicles are not only subject to ongoing change, but also give rise to further ethical issues and highlight important concerns about the future of society.

Empowerment also includes the ability to analyse and evaluate digital artefacts with a focus on intention and use through a critical, reflexive and constructive examination and understanding of consequences and their possibilities. This process of reflection and analysis is for digital artefacts what literature analysis is for novels, but with the additional liberating component of reframing and redesign. Underpinning this process is the realisation that digital artefacts are human-made and could have been designed differently had other perspectives been applied.

A particular type of application that has had significant social impact is ***social networks***, which now forms a primary infrastructure through which people interact. The fact that social relations are mediated by them offers the potential of benefits connecting distant people in greater numbers and offering advantages, e.g., in education, in professional development and in bringing comfort in many diverse ways. But they also have the potential to inflict damage, e.g. by manipulating public opinion, creating segregation of ideas and transforming people into products. The awareness of how this can happen by means of computing systems and the reinforcement of critical thinking are important elements to be developed in school education.

Whether they are driven by AI-based systems or not, ***automated decision-making*** systems (sometimes called ***bots***), which make decisions by purely technological means without human involvement or interpretation, pose increasing challenges to both education and society. They have the potential for both significant benefit as well as profound and social and economic change on a large scale, including disruption to the lives and livelihoods of individuals. Being aware of and recognising instances of automatic behaviour by computing systems is important, as is the ability to rehearse their recent advances in application areas such as healthcare, robotics, profiling, and shaping public opinion. This gives rise to possible applications across many areas as well as opening up discussion about the future of education, work and life.

Semi- or fully-autonomous machines, ***robotics*** systems, which can help/assist or substitute for humans and replicate their actions, particularly when the operating scenario is hazardous for people. In school education, they provide both a context for making concrete abstract concepts of informatics and a way to connect informatics to other sciences and technologies.

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[13] ACM Code of Ethics and Professional Conduct

[14] IFIP Code of Ethics

4.5 Examples of outcomes

This section together with annex A.2 introduces a small range of examples of high-level learning outcomes, appropriate for a reference framework. They are provided for illustrative purposes only, to show how this framework could be evolved in a more fully-fledged curriculum. They are not intended to be prescriptive, given the need of each country/region to design their own curricula in accordance with the requirements and constraints deriving from their school system. We are aware they are not comprehensive, and various national communities and different curricula developers might disagree on some of them and would have to add others. These are intended to stimulate thinking and action of curricula designers.

Primary education should be focused on encouraging pupils to “explore” foundational basic concepts of informatics (starting from “computing” phenomena directly connected to informatics systems and progressing to those connected indirectly) in their everyday life and to “ask questions” and to create solutions using simple tools and methods of informatics. They should be engaged both in “plugged” (implying the use of computing devices) and “unplugged” activities (without using digital technologies as appropriate to develop conceptual understanding).

As pupils progress through lower secondary education, they should learn more about concepts themselves (that is, considering “computing” phenomena independently from their connection to an informatics system). In this way, they should be educated to develop abstract thinking, to pay attention to requirements and should be involved in cross-disciplinary activities aiming at fostering their broader computational creativity and understanding.

In upper secondary education, pupils should arrive at an in-depth understanding of the core topics and develop a working practice in modelling simple actual scenarios while designing and developing solutions based on concepts of informatics. They should also appreciate related ethical concerns and be aware of the potential of informatics to underpin future contributions (including some to other disciplines).

Annex A.2 provides a limited range of specific examples of indicators of learning outcomes, appropriate for a reference framework. The outcomes are given at 3 levels: Primary (P), Lower secondary (L) and Upper secondary (U). The structure in annex A.2 reflects the structure given in the core topics (section 4.3). In a specific curriculum design, learning outcomes and goals may very well be described quite differently.

5. Concluding comment

It is hoped that this framework will be further developed over time and give rise to more research in refining ideas, in presenting them and, in so doing, sharing thoughts with the informatics education community.

The role of teachers who can inspire, who have insights and who can shape developments is crucial.

These matters will benefit from increased public exposure as well as support in all its forms.

Annexes

A.1 The discipline of informatics

Informatics is a distinct scientific discipline, characterised by its own concepts, methods, body of knowledge, and open issues. It can be synthetically described as the science of automated processing of representations. It covers the foundations of computational structures, processes, artefacts and systems, as well as their software designs, their applications, and their impact on society.

Through the digital representation of real-world objects, it helps the understanding of processes of modelling and manipulating them.

The informatics approach to thinking about problems and their solutions is of key importance for understanding our contemporary and future digital society, its advantages, limitations, and dangers. By supporting cognitive processes of human beings and mediating their communications, it can affect human life and social relations in fundamental ways.

Therefore, in providing a short description of the discipline, it is important to list both inward-looking (i.e., focusing on the discipline) and outward-looking (i.e., focusing on the impact of the discipline) aspects of informatics.

In the following, without aiming to be exhaustive, we list some of them, denoting with ‘computing system’ any system which carries out automated processing of representations.

Some fundamental aspects of informatics

Inward-looking aspects

- I-1. In a computing system, the processor component is able to automatically execute any given instruction of its programming language, which is an artificial language consisting of a small set of instructions.
- I-2. A computing system processes representations according to the sequence of instructions (program) expressing algorithms in terms of its programming language. A program is also a representation that can, as such, be processed by a computing system.
- I-3. While all computing systems are equivalent from the point of view of processing capabilities, they may differ in terms of many qualitative and quantitative criteria, and for some processing needs, there will never exist a computing system able to satisfy them.
- I-4. Computing systems can cooperate on processing activities and exchange representations. For this purpose, they need a common language, shared conventions (protocols), and interfaces.

Outward-looking aspects

- O-1. Choices regarding which information is represented and how it is processed are critical steps in the development of any digital computing system.
- O-2. Confidentiality, availability and integrity of representations are essential for the reliable use by human beings of any computing system. In general, protecting representations both inside a computing system and in the exchange with other computing systems is critical.
- O-3. Digital computing systems may be designed in many ways, resulting in affecting human and social life in different ways, which may embody designers’ own views, assumptions and biases.

A.2 Indicators of outcomes

In this annex we list a limited number of examples of indicators of outcomes, for each topic area of the reference framework (Table 1 in section 4.3). They are not intended to be prescriptive and are provided for illustrative purposes only, to show an example of the initial steps of the evolution of the framework in a more articulated curriculum and to stimulate thinking and action of curricula designers. Specific countries will take their own path to defining their own curricula according to requirements and constraints of their specific school system.

Data and information

P. Identify, with illustrative examples, ways in which computers can acquire data including automatic approaches and indicate how those data may be stored.

Visualise data in various forms and illustrate how this may be used to draw conclusions based on the data.

L. Identify a range of ways to access and process or manipulate data, giving attention to processing data so that it may be more effectively used, e.g., searched.

Describe features of high-quality data. Identify a range of additional ethical issues that may be associated with data collection such as bias.

U. Describe the need for protection of data in certain circumstances and explain how that protection can be provided with backup possibilities being included.

Describe ethical concerns associated with data collection, illustrating ways of enforcing adherence to ethical principles.

Algorithms

P. Identify a range of contexts in which sequences of instructions are designed and followed in everyday life and write sequences of instructions for everyday events.

Given a meaningful (to the pupils) sequence of instructions that a computer can execute, modify that in such a way that the instructions can still be executed and be of relevance; produce a succinct description of its functionality.

L. Write requirements for simple algorithms, develop algorithms and be able to scrutinise an algorithm to ensure that it does as it is intended.

Provide arguments to decide whether an algorithm is preferable to another solving the same problem.

U. Demonstrate familiarity with a set of simple algorithms, use abstraction to combine or generalise simple algorithms to solve more complex problems.

Assess algorithms with respect to quantitative and qualitative measures (e.g., efficiency and correctness).

Programming

P. Design, create, test and evaluate simple programs and determine whether they execute as intended; the programs may involve the use of conditionals and loops.

Identify and correct errors in simple programs.

L. Design, create, test and evaluate programs that demonstrate the use of simple algorithms, possibly accessing data from a sensor or reading data from a file.

Ensure that both programs and their specifications are simple and easy to understand as well as being mutually consistent; and use one strategy to assist with problem solving, and demonstrate its application.

U. Write routines to solve specific problems and demonstrate the ability to use routines in programs of their own creation.

Use decomposition to structure programs in a modular way.

Computing systems

P. Compare and discuss different types of input and output of computing systems.

Present conceptual knowledge of the major hardware and systems software of a typical computing system, name them and describe their purpose.

L. Compare and contrast a range of devices (including sensors, actuators, monitors, satellites) that can be utilised by computing systems and indicate possible uses of these.

Identify the main hardware and software components of a computing system and how they are related structurally and functionally.

U. Classify and describe the range of software and hardware that may be present in a particular computing system.

Understand the critical role of computing systems including embedded systems in society, and how they can impact behaviour and decisions.

Networks and communication

P. Distinguish between the Internet and the World Wide Web.

Demonstrate the use of search engines for retrieving information of various types.

L. Explain how data are transferred in networks.

Identify security issues associated with networks and explain how information on networks can be protected.

U. Explain the concept of protocols and their role in communication over a network.

Demonstrate conceptual understanding of layered network systems.

Human-computer interaction

P. Compare and discuss a range of ways in which humans may interact with computing systems.

Identify opportunities for improving the user interface of known software (including educational systems and games).

L. Explain, using examples, differences between interfaces designed for novices and those for experts.

Identify features of software that may prove problematic for users with special educational needs or disability.

U. Critically review a user interface.

Evaluate interfaces for users with special educational needs or disability and situations that would benefit from the use of more than one modality.

Design and development

P. Design iteratively simple digital artefacts.

Modify an existing design to explore alternatives.

L. Illustrate and present broad principles of design through an analysis of digital artefacts.

Analyse and discuss digital artefacts with respect to issues of inclusion and diversity.

U. Critique principles of design that differ depending on user characteristics. Additionally, highlight principles that are independent of user characteristics.

Apply principles of incremental and iterative design to redesign and develop new and useful digital artefacts.

Digital creativity

P. Suggest and discuss possible solutions for simple problems that might be solvable using programming.

Create simple digital artefacts and combine existing digital artefacts into something new.

L. Identify scenarios where programming or other computer-based tools are useful. Design solutions and compare their advantages and limitations.

Express own ideas through the use of programming or other computer-based tools.

U. Combine the use of digital tools to design and realise interactive digital artefacts.

Explore and reflect on the expressive capabilities of computational tools.

Modelling and simulation

P. Use simulators that model some aspect of the real world and discuss benefits and limitations of simulations.

Describe the scenario modelled by a simple program, and adjust the program to accommodate new aspects of the scenario.

L. Use, modify and create models or simulations to explore scenarios from the real world based on their own observations or knowledge from other school subjects.

Describe the static and dynamic correspondence between model and scenario and give examples of limitations of the model.

U. Characterise and discuss opportunities and dangers of advanced simulations (e.g., based on virtual reality or augmented reality).

Create computational models of scenarios and use these to make predictions and implications and assess limitations of the model.

Privacy, safety and security

P. Discuss concerns about safety and privacy of information.

Exhibit awareness for safety and privacy when using digital tools.

L. Identify and implement basic measures (e.g., involving passwords and their management) to ensure the security and privacy of information.

Protect computing systems from viruses and other forms of malware.

U. Illustrate how violations regarding security and privacy can endanger safety.

Exemplify difficulties arising from the existence of different legal systems and different cultures in providing guidelines on computer use and behaviour.

Responsibility and empowerment

P. Explain benefits and dangers of using the Internet.

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

L. 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.

U. 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.

References

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The Informatics for All coalition

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.

It is currently made up by the following organisations:

The ACM Europe Council aims to increase the level and visibility of Association for Computing Machinery (ACM) activities across Europe. The Council comprises European computer scientists committed to fostering the visibility and relevance of ACM in Europe and is focused on a wide range of European ACM activities, including organizing and hosting high-quality ACM conferences, expanding ACM chapters, improving computer science education, and encouraging greater participation of Europeans in all dimensions of ACM.

CEPIS is the representative body of national informatics associations throughout greater Europe. Established in 1989 by nine European informatics societies, CEPIS has since grown to represent over 450,000 ICT and informatics professionals in 29 countries. CEPIS promotes the development of the information society in Europe. Its main area of focus is the promotion and development of IT skills across Europe. CEPIS is responsible for the highly successful ECDL programme and produces a range of research and publications in the area of skills.

Informatics Europe represents the academic and research community in informatics in Europe. Bringing together university departments and research laboratories, it creates a strong common voice to safeguard and shape quality research and education in informatics in Europe. With over 160 member institutions across 33 countries, Informatics Europe promotes common positions and acts on common priorities in the areas of education, research, knowledge transfer and social impact of informatics.

IFIP was founded in 1960 under the auspices of UNESCO, as a federation for societies working in information processing. IFIP's aim is two-fold: to support information processing in the countries of its members and to encourage technology transfer to developing nations. As its mission statement states: IFIP is the global non-profit federation of societies of ICT professionals that aims at achieving a worldwide professional and socially responsible development and application of information and communication technologies.