informatics for all

Informatics Curriculum Framework for School

Interim version
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by

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Executive Summary

The contribution that Informatics has made in the past 80 years is impressive; accompanied by exciting technological advances, it makes fundamental contributions to current economic, educational, industrial and social development. These advances point to a future of even greater change.

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 curriculum 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 curriculum framework is described in section 3. A set of aims and objectives for informatics education for all young people is provided in Figure 1 followed by a set of core concepts and an accompanying brief description of these in Table 1; 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; 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. To conclude section 3, there are examples of how learning outcomes could be described in a concrete curriculum at three levels that reflect outcomes after primary, lower secondary and upper secondary education.

Section 4 addresses how the framework can be used for the purpose of the design of a detailed informatics curriculum. It addresses a range of matters including possible design shapes for a curriculum, the broad aims of a curriculum, the detailed intended outcomes, approaches to assessment, specific core concepts that provide structure to the curriculum and then learning activities. The learning activities themselves are structured around: what is known, what can be done, what can be done *with* others and what can be done *for* others.

The current document is an interim version and as such is incomplete. In presenting it for comment, the *Informatics for All* coalition has been mindful to include all the major elements that will feature in greater detail in the final report, while keeping it succinct.

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1. Preamble

1.1 Background

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.

Yet, within Europe, education in informatics is fragmented and receiving insufficient attention.

In its earlier work, the *Informatics for All* coalition[3] developed a *two-tier strategy*[4] 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 into 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.[5]

1.2 A common European curriculum framework

Recognising that within Europe education is a devolved matter, this document outlines a common 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

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

[2] See (White House 2016).

[3] informaticsforall.org

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

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

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 **curriculum framework** represents what we see as 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 and associated practices in informatics that all pupils are expected to achieve by the end of upper secondary education.[6]

In presenting the curriculum 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 tuned 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 which takes account (implicitly) of the aforementioned two-tier strategy for informatics in general education. Section 2 provides the context for informatics in society. Section 3 presents the curriculum framework itself: general aims and objectives, core topic areas and examples of outcomes. Section 4 provides guidelines for using the curriculum framework to develop concrete curricula.

[6] 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".

2. Informatics and Society

Informatics is the scientific discipline[7] that underpins the digital world. Given this 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, its advantages, limitations, and dangers (e.g., autonomous systems with possibly unexplainable behaviour, algorithms manipulating public opinion on social networks).

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.

Information technology differs from all other technologies that humankind has invented. Other technologies enhance our physical abilities, but information 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 way we live our lives in leisure time, during education and at work. Informatics in general, and the particular development of artificial intelligence (AI), 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 judgement from human beings to machines denotes the revolutionary aspect of informatics.

Therefore, we consider it important that future generations become equipped not just with user skills (digital literacy), but with the knowledge and skills of informatics bringing new ways of thinking about and tackling problems in both the real world and its digital counterpart. This is needed to bring about change, to contribute to the development of the digital environment and to ensure the evolution of a safe, secure, environmentally conscious and just society.

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

In this respect, we are aligned with the **European Commission**, which considers informatics education in school to be of 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 and enjoyable 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. 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.

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.

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

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

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

3. The Curriculum Framework

3.1 Introduction to the curriculum framework

While curricula should always be reviewed in the light of evidence and experience, we aim to 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.

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

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

3.2 Aims and objectives

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

At the end of upper secondary education, pupils can:

1. Understand the nature of computation that is directed at purposes in the real world involving both the problem and solution domain as well as mappings between these domains (representation and interpretation).
2. Understand and apply the fundamental principles and concepts of informatics.
3. Address needs and tackle problems by means of the tools and methods of informatics.
4. Analyse, frame and solve problems by devising formal representations, designing algorithmic solutions and implementing them in a programming language.
5. Design solutions *for* users.
6. Evaluate the potential benefits, as well as the limitations of applying a range of digital technologies to achieve a given task.
7. Express themselves creatively by using the tools and methods of informatics.
8. Use computational models to investigate, understand and communicate about (properties of) phenomena and systems.
9. Identify and discuss ethical and social issues associated with computational systems and their use.
10. Use digital technologies in a conscious, responsible, confident, competent and creative way.

Figure 1: Overall aims and objectives

Primary education should be focused on encouraging pupils to “explore” in their everyday life foundational basic concepts of informatics (starting from “computing” phenomena directly connected to information technology (IT) systems and progressing to those connected indirectly) 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 IT 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 understanding and creativity.

In upper secondary education, pupils should arrive at a good 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.

3.3 Core topics

In this section, we provide a high level and robust set of core topic areas that we consider essential for any specific informatics curriculum. These topic areas are all related to the aims and objectives listed in Figure 1, and should be cross-referenced with that list when developing concrete curricula.

The core topic areas are deliberately presented in succinct form using generic and invariant terms. This supports temporal robustness and accommodation of local priorities when translating the framework into 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.

Core topic areas	Description
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	Understand how to model and simulate natural and artificial phenomena and their evolution.
Empowerment	Critically and creatively explore and use digital artefacts and understand how personal and social life can be enriched by well-designed digital artefacts.
Ethics and social responsibility	Understand how individuals, systems, and society as a whole affect and are affected by computing systems, artificial intelligence, etc.
Privacy, safety and security	Understand risks when using digital technology, and how to protect individuals and systems.

Contemporary context and implications

As mentioned above, the topic areas in Table 1 are deliberately presented in succinct form. Whilst this ensures temporal robustness and accommodating local priorities when translating this curriculum framework, to illustrate the richness and relevance of the topic areas, we present a contemporary context and implications of the core topic areas:

Data. 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. Data about individuals as well as data about the world now form a routine part of life and can influence how people live. 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.

Programming, algorithms and programming languages. The combination of the concepts of programming, algorithms and programming languages underpin 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, underpins 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"[11] behaviour. This topic should provide an opportunity for pupils to explore a range of computer systems and to identify the impact of the application of requirements on its structure and functionality.

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 computer 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 cyber security. 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 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. But generally, in determining an 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.

Creativity, design and empowerment. This topic concerns the ability to use computing in creative, liberating ways and to acknowledge software as a creator and bearer of values and culture – that these aspects are explicitly or implicitly embedded in the software. Software is formed through design processes that include critical decision-making; 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. Creative design development includes also 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.

[11] By "intelligent", we mean behaviour that would be considered intelligent if exhibited by human beings.

Ethics and social responsibility. 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[12] or IFIP[13]). 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.

Modelling and simulation. This topic provides an opportunity to place an emphasis on the importance of abstraction, being aware of its advantages but also being aware of any limitations. 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. Even from an early stage of informatics education, pupils can use simulators in a variety of contexts to support their learning. 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.

Section 3.4 provides important additional material on the contemporary view.

3.4 Artificial intelligence

Artificial intelligence (AI) is a broad field whose study cuts across many of the core topics of informatics. Since the very beginning of thinking about how computers could work and their limitations[14], Alan Turing also considered whether machines could think[15].

Although there have been considerable developments in areas such as game playing, AI is again attracting attention for its rapid development, often driven by machine learning facilitated by the huge quantities of data now available. These recent advances have firmly established artificial intelligence as part of informatics. It is now seen as an essential technology with terrific potential for fuelling economic (and other) development. Thus, the questions about what artificial intelligence could mean and could cause are intrinsically tied to informatics.

From the perspective of informatics as a science, AI has always been seen as a driver for innovation and also for philosophical concerns: the latter include questions such as how far AI should 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, and so on. Compulsory informatics education should not only prepare pupils for the present and the future, but also provide a fascinating and timeless insight to informatics with many connections to other subjects by addressing AI in the curriculum.

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[12] ACM Code of Ethics and Professional Conduct

[13] IFIP Code of Ethics

[14] See (Turing 1936).

[15] See (Turing 1950).

Being aware of and recognising instances of “intelligent” behaviour is important, as is the ability to rehearse achievements of recent advances in machine learning, such as decision making, applications in healthcare, robotics, voice recognition, object recognition, recognising handwriting, 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.

In this context, software is not constructed in the traditional way, but through a process where systems infer their behaviour by looking for patterns or features in large sets of relevant data. This development has made it possible to automate an extraordinary range of tasks by enabling machines to play an increasingly decisive role in drawing conclusions from data and then taking action. The growing transfer of judgement from human beings to machines merits attention. Allied with this is a need to appreciate the consequences of using data with particular characteristics (e.g., unconscious biases), as well as any important related ethical issues.

It is important for pupils to understand concepts and various approaches to the development of AI, the comparison between AI and human intelligence and applications of AI in the real world including advantages, limitations and implications for society. Experiments with simple AI applications incorporating machine learning could facilitate such understanding.

3.5 Examples of outcomes

To further support the community and to strengthen the view that informatics should be taught from an early stage and at all stages of the curriculum, in the final report the intention is to provide descriptive examples of how expected outcomes for each topic area could be specified in a concrete curriculum at the three identified levels: primary, lower and upper secondary.

For this interim report, only three illustrations are provided for the areas of 'Algorithms', 'Data and information' and 'Networks and communication'.

Algorithms. Examples of outcomes for all three educational levels are:

Primary

Identify a range of contexts in which sequences of instructions are designed and followed in everyday life. Given a meaningful (to the pupils) sequence of instructions that a computer can execute, pupils should be encouraged to modify that in such a way that the instructions can still be executed and be of relevance.

Lower secondary

Identify the characteristics that would lead to one algorithm being preferable to another. Also recognise the need for a specification being associated with an algorithm and be able to scrutinise the algorithm to ensure that it does as intended.

Upper secondary

Gain familiarity with a set of simple algorithms. Also, be able to provide illustrations of simple algorithms that can be generalised (along with their specification) so as to be of wider relevance.

Data and information. Examples of outcomes for *upper secondary education*, related specifically to data collection, are:

Identify the need for protection of data in certain circumstances and explain how that protection can be provided with backup possibilities being included. Illustrate a number of ways in which data can be collected (also automatically), and identify any ethical issues associated with this.

Networks and communication. Examples of outcomes for *upper secondary education*, related to security and social issues, are:

Identify and explain some methods for protecting information entering a computer over a network. Also, outline the ethical issues associated with social networks and explain how these may be used to positive effect, such as supporting learning.

These examples indicate the generic nature of outcomes at the different levels of the curriculum framework.

4. Using the Curriculum Framework

This section focuses on pedagogical issues and related concerns that should be considered when using the curriculum framework for the development of concrete curricula. General pedagogical considerations are presented in section 4.1; specific challenges of maintaining a big picture on learning outcomes and designing for overarching features such as inclusion and diversity are addressed in section 4.2.

4.1 From curriculum framework towards concrete curricula – pedagogic considerations

Designing and developing a curriculum from a curriculum framework should take into account a number of underpinning features. Those features are, broadly: the design shape; the broad aims; the intended outcomes; and the ways in which curriculum outcomes might be assessed.

The design shape of a curriculum is a vital first step, as this is likely to determine the way in which details within a curriculum, including subject content and pedagogic approaches, is considered and how those details will be organised. A ***Linear*** curriculum is a sequence of interconnected links, with content usually studied only once; from an informatics perspective, this puts pupils at a disadvantage, as they should be able to apply their knowledge and practice to other problems, needs and situations. A ***Modular*** curriculum breaks the content into segments or sections, each one defining and covering a specific topic area; however, as informatics strongly relies upon an understanding of how one topic relates to others, links between modules need to be formed so that pupils fully appreciate and explore how one topic supports others. An ***Interactive*** curriculum[16] is designed to support pupil engagement through active participation in both individual and group work; for informatics, this is particularly useful, as informatics involves problem-solving and practice engagement with others in groups. An ***Outcomes-based*** curriculum starts from an identification of the **outcomes** of a course, year or module, and then works backwards to develop learning outcomes at each stage and for each teaching or learning session; for informatics, this is also a useful approach to take, as continuous development of long-term outcomes is crucial. A ***Spiral*** curriculum[17] allows pupils to revisit a topic, a theme or subject content a number of times, enhancing application or complexity on each occasion, with new content related to what has gone before; for informatics, this is a worthwhile approach, as it allows existing understanding and practice to be reviewed and applied in different, alternative and more complex situations. An ***Inverted*** curriculum[18] either inverts the idea of basic understanding being needed to develop practice, or inverts traditional outside-class activity with in-class activity; in this way, more commonly known artefacts and practices can be unpicked to develop deeper inner understanding, inverting the locations of passive with active learning so that more attention is given in class to supporting in-depth analysis and practice.

The broad aims of a curriculum should be considered prior to subject content; they are focused on pedagogical approaches. ***Practical activities with and without computers***

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[16] See (Franklin 2008).

[17] See (Johnston 2012).

[18] See (Pedroni & Meyer 2006).

allow pupils to explore informatics concepts and processes both through using computers and with hands-on non-computer-based activities that develop understanding of informatics concepts. ***Collaborative teamwork*** allows teams to solve problems and implement solutions, by learning through sharing, developing important social and life skills and competencies, all to be encouraged, rather than prevented. ***Creativity*** allows informatics activities to focus on creative concerns, rather than considering them as basic knowledge just to be learned and remembered, hence fostering enquiry and criticality. ***Abstraction*** enables informatics problems to be examined and addressed at various levels, removing the need to always take a bottom-up approach, allowing concepts to be examined in greater depth and/or through more complex problems, contexts or examples.

The intended outcomes of a curriculum can be grouped into four separate categories. ***What is known*** relates to the individual's understanding, often focused on the more conceptual elements of a curriculum. ***What can be done*** relates to the individual's practical competences and application. ***What can be done with others*** focuses on interactions in collaborative teamwork, achieved through practical activities with and without computers, with a class group or team. ***What can be done for others*** relies upon collaborative teamwork approaches working with others beyond the classroom, such as other pupils in the school, with friends or family, or with others in the community.

The ways in which curriculum outcomes might be assessed should relate back to broad aims and intended outcomes. ***Relating understanding*** can include verbal descriptions or reporting, written descriptions or answering questions, or drawing up models or plans. ***Showing physical outcomes*** can include assessing physical outcomes or artefacts. ***Relating group experience and outcomes*** might relate to how teamwork has been organised, how it has operated, and what has resulted. ***Reporting outcomes from external parties*** can assess what has been achieved, how external parties have played an important role in the end product, and how iteration and feedback have been involved.

Core concepts and content are a next stage of curriculum design, to consider the subject content of a curriculum. In this Informatics Curriculum Framework, the subject content is based around a number of core topic areas outlined in section 3.3. Taking the previous features concerned with curriculum design into account, it is then possible to formulate a more detailed structure that will form the basis of a curriculum, to further enable the creation of learning activities to meet the features chosen, which lead to learning outcomes. Examples of intended outcomes are presented in section 3.4.

Example learning activities related to broad pedagogic aims, intended learning outcomes and assessment can finally be developed when the previous curriculum design features have been considered and chosen, after a curriculum is mapped out through subject content areas with broad pedagogic aims and intended learning outcomes. Examples of possible **learning activities** about *data collection and analysis* that would support pupils at the various phases of education in one or more core topic areas are shown in Table 2.

This example of a recurring learning activity on *data collection and analysis* is related to several of the core topic areas in Table 1, including: 'Data and information', 'Algorithms', 'Programming', 'Modelling and simulation', 'Empowerment', 'Ethics and social responsibility' and 'Privacy, safety and security'. Meaningful learning activities are likely to relate to several core topic areas.

In this example, the curriculum design is interactive and outcomes-based, using elements of an inverted and spiral design where possible.

Table 2: Example learning activities related to intended learning outcomes within a specific subject topic area (data and analysis collection) for each phase of education

	What is known	***What can be done***	***What can be done with others***	***What can be done for others***
Primary				
Pupils can identify a range of ways in which different kinds of data may be gathered using a range of everyday devices (including sensors, monitors and satellites), and how those data are stored and used.	*Pupils explore weather reports, see how a weather station collects data and how they are recorded.*	*Pupils set up a sensor system to collect and record data on a computer.*	*Pupils work in a team to find out how to change the time variable for collecting data, to create three different output graphs.*	*Pupils show their parents/guardians how to use their mobile devices to capture and show data about changing locations using a GPS system.*
Lower secondary				
Pupils can explain the occurrence of bias in data collection and explain how this may be avoided. More generally, they can identify features of high-quality data. They can also identify a range of additional ethical issues that may be associated with data collection.	*Pupils explore graphs of data use recorded using different time intervals, analysing the differences and how these could affect interpretation.*	*Pupils can explore how a system provides data, identify bias, and amend the program in order to address this or to make its outcome biases transparent.*	*Pupils work in groups to create a system that shows ideas about levels of data confidence and data bias to the user.*	*Pupils work with an external group to explore levels of possible data bias and how they can identify ways to gather data to address biases where possible and to conform to ethical standards.*
Upper secondary				
Pupils can identify the need for protection of data in certain circumstances and explain how that protection can be provided with back-up possibilities being included. They can also illustrate a number of ways in which data can be collected automatically, and identify any ethical issues associated with this.	*Pupils explore how systems are created to offer automatic back-up of sensitive data.*	*Pupils can create a system that provides automatic data back-up.*	*Pupils work in a group to create three different ways to gather data, reporting on ethical issues and how these might be addressed in each of the three cases.*	*Pupils work with a group from another class to create a system to collect data on heartbeat rate changes during the day, to identify the time interval for data gathering that is most useful for that group, and to implement it.*

4.2 Additional considerations for developing curricula

In this section, we address the particular challenges of maintaining a *big picture* on learning outcomes and designing for overarching curriculum features such as inclusion and diversity.

The core topic areas of the framework have been identified on the basis that the objectives and topics can contribute to the development of a big picture of informatics and understanding issues associated with informatics and technology at many levels. Furthermore, these objectives and core topics have cultural significance and make it possible for pupils to develop self-efficacy in relation to informatics and using technologies.

As new technologies develop, new approaches and tools emerge. It is all too easy to become lost in discussing possible implications and detail and to lose sight of the overall aims and goals of what pupils should learn. By making use of a big picture of informatics and the use of informatics that pupils need to acquire by the end of secondary education, curriculum designers will be enabled to focus on what is important for inclusion in the curriculum (see Annex A.2 for further detail of how fundamental ideas are important for leading to a big picture as well as resolving other issues in curriculum design).

Considering the overall picture of learning objectives and core topics in a curriculum specification makes it possible to ensure that the description at the top level is accessible to all stakeholders. However, as discussed in section 4.1, a detailed curriculum specification also needs to define concepts and content within a broader frame of the design shape, design aims, intended design outcomes, and ways in which curriculum outcomes might be assessed.

From overall aims and goals, curriculum design can be approached in different ways. One approach is to take each objective or core topic and to identify the smaller elements that need to be developed in order to enable understanding of that objective or topic. Such an approach might begin to map out possible learning pathways and progression. Whilst this approach is consistent with an ‘outcomes-based’ approach discussed in section 4.1, there are other important and general design approaches discussed in section 4.1 that should be carefully considered.

A big picture of objectives and core topics should be used as a check to ensure that all of the material covered is relevant, and therefore deserves to be included in the curriculum for all pupils. This focus will help to avoid overfilling the curriculum, as well as ensuring curriculum relevance for all pupils. In this context, other important considerations need to be made at the design stage, rather than as add-ons later. These important considerations include the need to accommodate diversity and inclusion.

In an informatics curriculum for all, diversity and inclusion issues are crucial, including the important issue of gender balance. In general, inclusion should be considered in order to avoid exclusion of certain groups of pupils. Under-representation of women in informatics and STEM[19] more generally has long been recognised but more recently under-representation of other groups has become an important issue. While the issues are complex

[19] STEM: Science, Technology, Engineering and Mathematics.

and varied and extend beyond curricula considerations, much is now known about key factors[20, 21, 22] for promoting diversity through curriculum design.

Ways to support pupils who may have special needs, should be considered at the point of curriculum design. Some ways to support pupils are already known[23,] and these should be referred to and integrated into learning approaches and activities. In relation to informatics education specifically, research has indicated that designing engaging practical activities and using tools such as educational robotics can make the subject appealing to all pupils.[20]

Particularly with respect to gender, research has indicated that girls in general tend to be interested more in people – the purpose and use of technology – whereas boys in general tend to be interested more in things – the devices themselves.[24] Thus, it is important to ensure that the human and real-world relevance of curriculum activities is emphasised. Teachers play an essential role in setting up learning environments that engage all pupils naturally as well as choosing gender-sensitive examples and approaches. Furthermore, engagement with informatics at an early age can promote self-efficacy, which is particularly crucial for girls[25] and tackle gender stereotyping before prevailing views become entrenched.

[20] See (Peixoto et al. 2018).

[21] See (Archer et al. 2020).

[22] See (Aguar et al. 2016).

[23] For example, for auditory, visual, motor disabilities and autistic spectrum disorder.

[24] See (Marcher et al. 2021).

[25] See (Aivaloglou & Hermans 2019).

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 Fundamental ideas in informatics education in school

The role of big ideas in curriculum design

Educators in other subjects like mathematics and science education have advocated the notion of “big ideas” in order to focus curriculum design.[26] Motivation for the identification of big ideas was to provide a rationale for replacing an overcrowded and fragmented science curriculum with an approach for how to achieve progression towards understanding key ideas – “big ideas” – of relevance to pupils’ lives during and beyond school. The value of big ideas in mathematics education is considered not only to prevent curriculum overload but also to connect seemingly disparate areas of mathematics learning in order to develop a big picture that enables deep and powerful learning.

Also, for informatics education, there are advocates of a big picture approach to the school subject.[27] This is used to appreciate a scientific discipline with longevity, rather than a technology discipline that needs to change every time a new technology develops. Furthermore, according to Bell et al., the big picture helps curriculum designers and other stakeholders to see the long-term value of the subject.

There is no agreed definition of big ideas for informatics education, but prior to these discussions of big ideas in the literature, Schwill had presented a similar “ideas-based” approach to curriculum design[28] based on Bruner’s exposition of *fundamental ideas*.

For Schwill, a fundamental idea of informatics is “a schema for thinking, acting, describing or explaining” which: (1) is applicable or observable in multiple ways and in different areas of computer science, and organises and integrates a wealth of phenomena; (2) can be taught on every intellectual level; and (3) has longevity and has meaning in everyday life.

In defining big ideas, we build on the work of both Bell et al. and Schwill and have adopted Schwill’s definition of ideas[29] as distinctly different from concepts in various ways, but in particular, ideas are dynamic, whereas concepts are static; ideas give the motivation to create concepts. In identifying ideas in informatics that are valuable as big ideas, we have considered five essential characteristics (criteria) of big ideas. A big idea must:

1. Have a broad explanatory power in relation to a large number of objects, areas, events and phenomena that are encountered by pupils in their lives during and after their school years.
2. Provide a basis for understanding issues at any intellectual level, such as autonomous decision systems that have the potential to influence every part of life, business and education.
3. Have longevity: they are expected to remain relevant for many years and are not tied to current technologies.

[26] See (Askew 2019; Harlen 2015).

[27] See (Bell et al. 2018).

[28] See (Schwill 1997, p. 286).

[29] See (Schwill 2004).

4. Make it possible to develop self-efficacy and to raise enjoyment and satisfaction in being able to find answers to the kinds of questions that people ask about technological solutions and limitations in everyday life situations.
5. Have cultural significance – for instance, in affecting views of the human condition – reflecting achievements in the development of technology, and the impacts of technological developments on societies.

Towards big ideas in informatics

Our vision of informatics education is that at the end of secondary education every pupil is able to grasp a set of 'big ideas' of informatics and how it is used, and hence has developed a big picture of informatics and its relevance in the modern world.

In identifying some potential 'big ideas', we have considered the five essential characteristics (criteria) outlined above. Figure 2 presents some potential big ideas of informatics.

1. Information has to be represented as data in digital form so that it can be computed.
2. Modelling is a core activity of informatics. It is the process of creating a representation of certain aspects of reality or ideas for a particular purpose.
3. Designing digital systems is a complex process focusing on serving human needs, ease of use and paying attention to security, privacy and ethical issues.
4. Algorithms interact with data to solve computational problems.
5. Algorithms need to be expressed as programs to be executed by a computer.
6. For most problems, there are many different algorithms and programs possible to solve this problem. And for some problems, there will never be an algorithmic solution.
7. All computer networks – including the Internet – consist of many different computing systems that can cooperate and communicate because of shared conventions to process and transfer data.
8. Some programs are written so that they can modify their models or algorithms autonomously, based on a large amount of data. And in doing so, their behaviour may appear as 'intelligent' and may become difficult to predict and to explain.
9. Harnessing significant amounts of carefully targeted data and analysing them can create great insight, lead to improved practice and even lead to innovation. However, care has to be taken over the quality of data.
10. Applications of informatics often have ethical, social, economic and political implications.

Figure 2: Potential big ideas of informatics

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