Building on the Informatics Reference Framework for School

Potential contemporary themes towards development of an informatics curriculum

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Executive Summary

The Informatics Reference Framework for School provides 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.

This document is a supplement to the Informatics Reference Framework for School. The intention is to support the interpretation of the Informatics Reference Framework in the context of recent innovations in informatics so that curriculum designers are encouraged to address contemporary themes of informatics and issues arising to help to match the curriculum to the interest of learners.

Specifically, the focus is on the themes that are highlighted in bold italics in Section 4.4 of the Informatics Reference Framework for School. These themes are 'opened up' for attention in the current document as the basis for further development, in such a way that the concept of a framework is retained, although learning outcomes and aspirations are less formally addressed.

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1. Data science

There is increasing recognition of the role that data can have in informing decision making and guiding advances leading to important innovation in areas such as health, the natural sciences and business intelligence as well as education. The identification and gathering of relevant data as well as the utilisation and processing of those data are important aspects of the subject of data science.

Data can take various forms including text, multimedia (sound, video, etc.) and sensor data collected, for example, through Internet of Things (IoT) networks. Digital devices can be used to collect data both for real-time analysis (e.g. health monitoring) and for retrospective analysis (e.g. for business intelligence for governments and/or industry). It is important to ensure the quality of collected data including its relevance; often those data should be carefully protected and used with caution. Data about individuals as well as data about the world now form a routine part of life and can influence how people live. Collection and the 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 many areas including business, education 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, legal and sustainability issues associated with the collection and use of data with security, privacy and confidentiality often being prime concerns. Training of big artificial intelligence models, for instance, can require computing power and processing time that involves vast resources in terms of cost, energy, etc. These various considerations need to be included in a contemporary view of informatics education. The many aspects include: data collection, cleansing data to remove extraneous detail, data quality including attention to such matters as bias, confidentiality, visualisation of data, structuring data and accessing data.

Even from an early age, pupils ought to be encouraged to address issues associated with high quality data and be engaged in relevant innovative practical activity. Suitable collections of data, also country-specific, can typically be found on the Internet.

2. Programming languages

Programming languages have been developed to facilitate the development and understanding of programs to be executed reliably on computers.

Over the years, the family of programming languages has grown in number and in sophistication. There is now an expectation that languages should be easy to understand, have a desirable level of expressive power, and should support the identification of errors as far as possible. Languages for more advanced programming should have libraries that support the development of a range of software, e.g. for topics such as graphics, mathematics, concurrency, and data science.

Languages are typically described using syntax and semantics. The syntactical rules resemble the rules of grammar in natural language and the semantics explain the meaning of syntactically correct programs. To be executed, programs expressed in these languages are translated into machine code (or virtual machine code) by a compiler or interpreter. The initial phases of the compilation or interpreting process involve checking that the program is syntactically sound and, if not, then errors are highlighted.

Some languages have been developed for pupils of all ages. For instance, for younger pupils, turtle graphics are attractive and form an element of the LOGO language. The language Scratch is a block-based visual language and typically regarded as being suitable for young children.

Over time, languages were developed to support various paradigms of problem solving: procedural, functional, logical and object-oriented paradigms. More recent languages have been developed to support particular needs.

Programming should form part of informatics education for all pupils. Efforts by teachers to ensure that programming is enjoyable enhance pupil engagement, and the creative element should be highlighted whenever possible.

3. Artificial intelligence

Artificial intelligence (AI) is about building “intelligent” systems. This process is to be interpreted as building systems that mimic certain aspects of human cognitive skills. Much of the history of AI has been devoted to the exploitation of logic to make deductions and inferences from known information. But recent major advances have occurred through developments in machine learning. This has resulted in systems that, for instance, can advise, control, reason, deduce, make certain decisions, recognise objects, recognise speech, recognise handwriting, process language and can “learn” by being trained or by building their own model that is consistent with a given dataset.

In many walks of life, artificial intelligence is now seen as a field of research and development that will significantly transform many aspects of the economy as well as daily lives. From this perspective, it is desirable that a study of informatics should acquaint pupils with these developments but especially as they may affect their future. Exploring and discussing these developments will inspire pupils and motivate them to examine how to create a better society.

Behaviour regarded as ‘intelligent’ gives rise to the development of systems that can act autonomously or can augment human capability. These include autonomous vehicles for transport including space travel, personal assistants, recommender systems, as well as developments in industry, education and robotics. Understanding their capabilities opens up discussion about many social issues including the future of work. In all cases, the impact and associated ethical concerns merit special attention.

From an educational perspective, tasks for pupils might include identifying instances of intelligent behaviour and explaining relevant social and ethical issues, developing simple AI systems, drawing comparisons between artificial intelligence and human intelligence, and suggesting they can be mutually supportive.

4. Machine learning

Recent advances in machine learning enable systems to identify, by various means, features and patterns in large sets of unstructured real-life data. These developments - enabled by better algorithms, improved hardware and ever larger collections of digital data - have made it possible to automate an extraordinary range of tasks by enabling computers to play an increasingly decisive role in drawing conclusions and taking action on the basis of data. Thus it is important for everyone to develop insight into the nature of machine learning; undoubtedly, young pupils can engage in practical activities using simple data-driven algorithms of the type that drive machine learning.

There are numerous approaches to implementing machine learning systems; many are based on exposing them to large sets of examples and using some form of “reward” for building appropriate models.

This process of “learning” can happen in either an online setting or an offline setting. In the former, the system is developed offline and launched into a live setting only when it has been tried, tested and checked for quality. In an online setting, the systems are still developed in an offline setting but once deployed they continue to enhance their capability through a “learning” process. Given that the outcome of these systems are entirely dependent on the data they have examined, the quality and reliability of those data are of the utmost importance. It is important to avoid data with particular characteristics (e.g., unconscious bias), or data that lead to discrimination or injustice.

From an educational perspective, in recent years, a number of environments have been developed to enable people, including young pupils, to begin to explore machine learning and thus to develop understanding of its nature, capabilities, and limitations; see, for example, https://code.org/oceans. It will be important for curriculum developers as well as teachers to identify suitable resources in their own contexts in order to enable pupils to develop their understanding of concepts of machine learning (e.g., features and their extraction, unsupervised or supervised learning) through practical activities. Moreover, great attention should be paid to the fact that the particular way these systems are built makes their testing and verification highly challenging and exposes them to the so-called “adversarial approaches”, where clever modifications to data presented to the systems leads them to derive wrong conclusions or decisions. In some cases, even altering the sequence in which data are examined during the “learning” phase can produce systems making different decisions.

All pupils might be expected to recognise that the growing transfer of judgement from human beings to machines merits continued attention and includes the human computer interface issues associated with cooperation between humans and machines.

5. Computer graphics

Visual rendition of program interfaces is more ubiquitous nowadays and is of considerable interest to pupils; they are used to interact with smart devices where graphics are widely used. Therefore, it is important to provide some element of knowledge of the fundamental issues related to this theme.

For pupils of an appropriate age, the basic approaches to image formation (vector and raster) and colour modelling (additive and subtractive) are interesting enough, can be treated at a level they can understand from their existing knowledge base, and may be well anchored to traditional artistic drawing activities.

Going forward, and again with the advantage of making reference to what pupils do in manual drawing activities (i.e., drawing with the use of perspective), problems related to the projection of 3-D scenes on a 2-D surface can be addressed. Also interesting and suitable to a treatment with various levels of complexity, is the “anti-aliasing” technique to improve the visual aspects of texts and shapes.

When pupils develop higher levels of understanding and application, the theme can benefit from a background in geometry and aspects of physics, e.g. to understand how light travels, is reflected and passes through certain matter, how shadows occur, how objects behave after collision, and so on. In addition, the issue of graphical manipulations and their relations with algebraic transformations offers a lot of possibilities for discussing what happens every second in modern games. Programming simulations would tend to be accessible only to those in the later years of their school education and, most likely, to those who have followed a scientific route, the reason being that supporting knowledge tends to be taught at that later stage of education. Here, there are clear relations with simulation activities and a natural possibility of referring to other scientific phenomena.

Once a working knowledge of basic aspects has been gained, pupils should be introduced to the graphical facilities in programming languages with attention being given to libraries to support graphics development and the use of these. Pupils at the later stages of their secondary education might be expected to demonstrate the applicability of graphics libraries in support of a project.

6. Virtual reality

Virtual reality (VR) is about having a simulated environment in which a user can feel immersed and is able to interact with the environment and/or with others within the environment. The simulated environment is computer generated and may model either the real or an imaginary world. Ideally, the environment should have a 'natural' feel, so that users do feel they are present in a natural environment. Thus, VR environments are significantly different from more traditional applications and learners should gain understanding of their advantages and challenges.

There is an ever-expanding range of important areas of applications of VR including: medicine and healthcare, navigation, education and training, exploring buildings and geographical locations, as well, of course, games and entertainment. There are particular benefits when the simulated environment reflects a potentially dangerous or sensitive situation, e.g. life-threatening surgery or flight simulator, where a sudden or frightening situation may provoke a considerable physical reaction in the user and monitoring of that may be desirable. There are both ethical and wellbeing/ergonomic issues in the development of virtual reality applications, e.g. games that make the user perform activities that are completely unethical in the real world.

Through experience of using VR systems, pupils should be expected to identify their benefits but also their limitations in particular application areas. Also, pupils should be able to identify situations that would benefit from the deployment of VR technology providing justification, and suggest materials that might be utilised in the creation of a system.

Pupils can learn aspects of informatics, including programming, by working collaboratively within an immersive environment, thus potentially being more motivated. Through these experiences, they can also discuss and gain understanding of aspects of human computer interaction and the design of different types of interfaces.

7. Augmented reality

Whereas virtual reality involves the creation of a wholly virtual world, augmented reality is about enhancing the real world with live updated layers of digital content aligned to the physical environment. It involves the creation of an environment in which objects of the real world are augmented or overlain or enhanced by digital objects as if they existed in the same (mixed) space.

Augmented reality is based on camera technology and computer vision mounted in the environment. Typically, the aim is to experience the real world but at the same time to draw attention to specific visual qualities, aspects of behaviour or performance, features or characteristics, e.g. to see a piece of new furniture or a kitchen design in your own home before you buy it, to see a working set of instructions on how to assemble or dismantle industrial products to be serviced, to view head-up displays used for navigation or, in a healthcare setting, pointing to part of the human body to reveal details that had been gathered via a scan.

It is expected that applications of augmented reality will grow considerably in terms of frequency and impact, the latter being driven in part by advances in technology.

Through a disciplined approach in critically reviewing instances of augmented reality, pupils should be able to identify and describe additional applications, justifying them in terms of possible benefit and impact and to modify systems towards new applications.

8. Social networks

The term social media (or social networks) refers to a collection of Internet-based systems or networks that utilise the ubiquitous presence of the Internet in every digital device to facilitate social interaction between people. There are many such systems, but they tend to be characterised by the ability to smoothly establish connections between people, making it easier to communicate (also in groups), to instant message, to share video, pictures, information and photographs. The benefits of these systems include establishing valuable networks and sharing ideas, developing new interests, learning new concepts, and being entertained.

Privacy is a fundamentally important concern in the context of social media. In their enthusiasm, there is a temptation for users, often especially young people, to include a great deal of information in their profiles including photographs and their views on particular topics; they may later come to regret this and fail to understand that all these data can be used to inadvertently nudge them to always repeat the same kind of choices.

A second concern is the ad-driven business model of many of these platforms, where the goal is to increase as much as possible the time of engagement with the platform itself. This increased exposure to ads tends to reinforce one’s own view and to create the so-called “echo chambers”; in these “echo chambers”, the diversity of opinions users are exposed to is largely reduced, resulting in highly polarised communities and reduced critical thinking abilities.

Finally, given their incredible potential of amplification of shared information, coupled with the detachment given by interacting through a digital device, the third important point concerns pupils’ needs to be aware that social media platforms can easily become a means of discrimination, bullying and exclusion. These problems are particularly critical for young people whose identities are undergoing rapid development. They need to know of potential ways of addressing these issues.

From an educational perspective, young people tend to be drawn to social media. Consequently, this is likely to be a topic of considerable interest to them. However, while they can provide enrichment to the social aspects of education relating to social media, utmost attention should be given to potential downsides of social media.

9. Automated decision making

In automated decision-making situations, decisions are made by computers without any involvement of humans. Such decisions are normally based on deductions derived from analysing (perhaps large volumes of) data, and the quality and relevance of those data tends to have huge significance.

Computers have demonstrated capability in decision-making by being able to consistently beat world champions in complex games such as chess and Go. This ability has been achieved by feeding large amounts of data about previous games to machines which then analyse the data and so build up relevant knowledge including tactics to be employed, for instance. As the computer is able to analyse all possible moves and their consequences within milliseconds, the computer is able to compute the best move including unusual moves not commonly employed by human players.

The choice of data that forms the basis of the underlying analysis is of central concern. There should be no bias, for instance; it should be complete in covering important aspects of situations that are likely to arise; and it should reflect the context in which the eventual system is to be deployed.

Automated decision-making is used in applications such as: making decisions about medical diagnosis following analysis of, for instance, x-rays; making decisions about sentencing in judicial situations; navigating in, for instance, the context of driverless cars. In these situations, automated decision-making may be used to augment human decision-making or even to replace it.

Such advances can raise ethical concerns. Here it is important to distinguish between irreversible real-time decision-making (e.g. as in driverless cars) and offline decision-making. The latter might include selecting relevant historical court cases to be used by a human lawyer in a defence case for a suspected criminal action, or a decision on which x-rays analysed by artificial intelligence or machine learning should be further assessed by a human doctor and which x-rays do not require this.

From an educational perspective, pupils could be asked to: identify applications that involve machines in decision-making, both autonomously and in partnership with humans; develop a simple autonomous decision-making application; argue the merits or otherwise of being able to override autonomous systems; address ethical guidelines for automated decision making.

10. Robotics

A robot is a computer-based mechanical machine designed to undertake tasks that assist or even replace humans (especially in hazardous operating scenarios) or can even be used for entertainment. Besides algorithms and programming, the field relies heavily on many branches of engineering including but not limited to electronic engineering, computer engineering, and mechanical engineering. They can be static or mobile and all rely on a range of sensors (to perceive their environment) and actuators (to interact effectively with their environment).

In addition to robotics, physical computing systems are finding a larger role; home automation is taking place in emerging smart home systems and personal assistants. In these systems, microcontrollers, sensors and actors are ubiquitous elements working together with an Internet connection.

With many applications, robots and physical computing systems operate autonomously, but the possibility of them operating in partnership with humans also exists, e.g. in robotic surgery or in dangerous applications. In all cases, human computer interaction considerations are vital, and an important aspect of that is eliminating potential harm to human beings who are co-operating with or affected by the robots. More recently, humanoid robots - whose appearance mimics that of humans - are being developed and, in these cases, interaction considerations are even more important, especially when these robots relate to children. For example, robots have been used to support children both socially and emotionally, and for language learning. In these instances, care is taken to monitor consequences in terms of children's emotional and social development.

In an educational context, robots and physical computing systems are available for quick and hands-on introductions to informatics and provide a way of making the result of programming highly visible. Pupils can gain visual feedback on the effectiveness of their programs. Coding of robotic pets such as a bee or a turtle or physical computing systems (programmed with microcontrollers) is a common way of introducing young children to programming and is proven to enhance interest and self-efficacy of pupils of all ages because of the instant and direct feedback while programming them alone or in pairs. To strengthen their capabilities, these systems can be taken home to engage feedback and support from the family. Generally, their software support for education is a lively and important area of development. Moreover, competition with robots in various fields (e.g., football, dance) is an educational way of engaging pupils with a variety of aspects of informatics.

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.