Designing and Implementing a Concrete Informatics Curriculum for School

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by

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Executive Summary

In order to benefit from the Informatics Reference Framework for School[1], and to implement it successfully for the benefit of pupils in each country, two main tasks need to be addressed. Firstly, it is of utmost importance to have well-educated teachers of informatics. Secondly, it is also important to have concrete curricula designed to take into account particular situations and needs in each country, as well as accommodating age and appropriate stages of development of pupils. General curriculum design approaches and pedagogy should be tailored to the specifics of informatics. Some ideas and experiences to guide decision makers and curriculum designers in this respect are presented in this document.

This document focuses on pedagogical issues and related concerns that should be considered when using the Informatics Reference Framework for School for the development of concrete curricula. Factors to consider in the development of well-educated teachers are presented in Section 3.1; general curriculum design considerations are presented in Section 3.2; and specific challenges of creating learning activities, learning outcomes and designing for overarching features such as inclusion and diversity are addressed in Section 3.3.

In some respects, curriculum development in informatics is not different from, for example, science that might appear in primary education, or physics that might appear in secondary education, as it needs to consider theoretical as well as practical aspects. As has been importantly stated[2]: “children learn by doing and by thinking about what they do”. The position of informatics in a curriculum also needs to align with other curriculum areas, so there is a need to take account of the same or similar concerns that apply to other subject areas.

An informatics curriculum should be designed for all pupils; equality, diversity and inclusion issues are crucial, including the important issue of gender balance. Inclusion should be carefully considered to avoid exclusion and to ensure engagement of all pupils.

In this document, to make the curriculum development as ‘informatics-specific’ as possible, informatics examples are provided throughout.

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[1] See (Caspersen et al. 2022).

[2] See (Papert 1980).

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1. Developing a well-educated teacher workforce

Teachers are the cornerstone of the implementation of any curriculum. Whilst this applies to all disciplines, there are complexities with informatics, because of the need to be aware of how the theoretical and practical facets of the discipline can be interrelated, especially with the fast development of the discipline. Designing a curriculum should consider how to involve teachers, and to consider what the prerequisites of teachers certified to teach informatics should be.

An important point to consider is that early enthusiasm in using technology in the past has led to overestimating the importance of digital skills, and consequently this deprived pupils of learning informatics. A natural consequence was the idea that teachers could be 'trained' to teach digital skills. It is becoming generally accepted that, besides digital skills, informatics and informatical thinking needs to be part of a general education for everyone. As a consequence, there is a need to have informatics teachers educated in informatics (at least at the level of a Bachelor's degree in informatics for teachers in lower secondary and upper secondary school), combined with or followed by pedagogy and methodology support for teaching informatics concepts. This is already implemented in some countries (e.g., in Slovakia since 1982, in Israel since 1995, and more recently in the United Kingdom (UK), Switzerland, and the United States of America (USA)).

It should be recognised that educating teachers takes time. Interim measures can be suggested and implemented to allow early introduction of informatics to schools, but the limitations of these forms of implementation need to be considered at the outset. Reasonable expectations need to be set for all parties concerned.

While the conceptual underpinning of the informatics discipline is based on stable foundations, digital technologies and associated practices are subject to evolution and development, which teachers need to be aware of and address when designing and implementing a curriculum.

Whilst there are pre-requisites to becoming certified to teach informatics, and these need to be covered for pre-service teachers, there is also an ongoing need for in-service training, because of the fast development of the informatics discipline. The Computer Science Teachers Association (CSTA), for example, has addressed the important issue of informatics teacher preparation and certification through the work of a special task force.[3]

Teachers may need to cope with teaching pupils whose knowledge or skills in some practical aspects of digital technologies is greater than their own. Informatics teachers can also suffer from isolation. If there is only one teacher per school, this can result in a lack of a teachers' community. Additionally, since the field of informatics education (and especially in schools) is relatively young, its related research is even younger[4],[5], so there is a limited scope of professional (content-pedagogical) literature.

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[3] See (CSTA 2020).

[4] See (Gal-Ezer and Stephenson 2010).

[5] See (Ragonis and Oster-Levinz 2011).

Effort should be devoted to forming communities of informatics teachers who can convey the nature of the discipline. Appropriate financial resources need to be allocated to support these efforts. Informatics teachers' centres, for example, can empower informatics teachers and enable them to face the challenges of a constantly changing world of computing. Additionally, mentoring of schoolteachers by university teachers, provision of online courses and support, and strong linking of pre-service teacher institutions with schools have also been used to develop wider teacher involvement and practice.

In terms of scaffolding of teacher practice development, teacher education and models for implementation, appropriate ways forward are likely to depend on the existing infrastructure available, whether there are national computer societies and associations, regional or municipal centres, or more local sharing across groups of schools. It is vital that managers and decisions makers explore possible avenues for teacher development at early stages of curriculum design and implementation.

2. Designing informatics curricula

Some examples of developing (parts of) concrete informatics curriculum are presented in this section. These are based on more general curriculum design principles (briefly described in Section 3, and adapted for some particular needs of informatics.

Moving from an informatics framework towards concrete curricula – pedagogic considerations and curriculum design. Designing and developing a curriculum from a reference 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. For each of these features, age and development of pupils is always a key concern. Curriculum designers at different stages of school education are concerned often with design shape and broad aims, but they may not always be concerned with assessment issues, as these are linked more to activities that are conceived by curriculum implementers directly (by teachers).

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. Different design shapes should be carefully considered with informatics, due to theoretical as well as practical aspects that need to be appropriately covered. Design shape is an initial curriculum concern that should take into consideration the age of the pupils (as should those concerns that follow). A brief description of different design shapes follows.

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. For example, if ethics and social responsibility are only considered at one specific time, then the relationship between ethics and social responsibility with networks and communications could be divorced and not fully developed; the importance of the context could be lost. There is a need for greater integration of learning for pupils that goes beyond a linear curriculum. If pupils learn only theoretical issues first, and then practice comes at the end of their studies, it is a disadvantage. Theoretical and practical issues need to be interwoven at all stages.

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. For example, digital creativity has a part to play in practical activities of modelling and simulation, so having a module devoted to digital creativity might not allow this important practical focus to emerge.

An ***Interactive*** curriculum[6] is designed to support pupil engagement through active participation in both individual and group work; for informatics, this is particularly important, as informatics involves problem-solving and practice engagement with others in groups. Taking all core topic areas, active participation and engagement should be developed

[6] See (Franklin 2008).

appropriate to age.

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 a useful approach to take, as continuous development of long-term outcomes is crucial.

In developing this design of curriculum, a starting point is often to consider the respective elements of the curriculum, how they might relate, and then to identify specific outcomes that would be desirable for specific ages. A suggestion of outcomes is identified in the Informatics Reference Framework.[7]

Considering the key needs of an informatics curriculum, an interactive curriculum as well as an outcomes-based curriculum would be appropriate.

A ***Spiral*** curriculum[8] 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[9] 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. This is an important approach with informatics, but needs to be developed in national, regional and local contexts, accommodating the cultural and social environments in which pupils and teachers work. An example is shown in Table 3.1.

Table 3.1: Example of inverted activity

Prior to a classroom lesson	Exploring the forms of data and algorithms that are used to simulate responses to a volcanic eruption, and considering how this relates to the local way of responding in this volcanic region
In the classroom lesson	Discussing what amendments would be needed and exploring how the simulation could mirror local experiences more, and accommodate the needs of those responsible for ensuring public safety

Any curriculum design also needs to consider hurdles that any implementation has to overcome. For example, there is a period of implementation when curricula for different cohorts of pupils are needed, and the way that these emerge and coalesce needs careful monitoring and review. Similarly, it is crucial to plan for teacher education (an issue that is considered in the last section of this document).

The broad aims of a curriculum should be considered prior to subject content; they are

[7] See (Caspersen et al. 2022).

[8] See (Johnston 2012).

[9] See (Pedroni & Meyer 2006)

focused on pedagogical approaches. There are four important pedagogical approaches that should be considered when setting up learning activities.

Practical activities with and without computers 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. Practical activities should go beyond coding and programming; they should involve, for example, online and onsite exploration, as well as reviewing outcomes and gathering evidence about uses and applications. For example, for a non-computer-based activity, finding the 'secret number' in a bar code, or for a computer-based activity, creating your own computer game.

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. Collaboration should be developed from early ages; pupils need to be able to develop skills and understanding about working as pairs, in groups, and in teams. For example, creating your own computer game can involve a team, with different individuals contributing in different ways.

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. For example, thinking about problems that they have, or others have, and how to solve them through informatics can develop creative approaches. An example might be creating a sensor system that can gather data at different heights as a balloon rises through the air.

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. For example, using previous experience to break down a more complex problem of coding a program to create a ten-sided figure.

3. General curriculum principles and implementation

Developing a curriculum from a curriculum design should take into account a number of underpinning features. Curriculum implementers are concerned often with an overview of the broad aims; the intended outcomes; and the ways in which curriculum outcomes might be assessed.

The broad aims of a curriculum relate to the core topic areas of the Informatics Reference Framework for School[10], but it is important for implementers to see how these relate to a big picture of informatics, and understanding issues associated with informatics and technology at many levels.

As new technologies develop, new approaches and tools emerge. It is all too easy to become lost in discussing detail and possible implications, and to lose sight of the overall broad 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.

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 2, 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.

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 when following the design stage and developing the implementation stage, rather than as add-ons later. These important considerations include the need to accommodate equality, diversity, and inclusion.

In an informatics curriculum for all, equality, 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[11] more generally has long been recognised, but more recently under-representation of other groups has become an important issue. While the issues are complex and varied and extend beyond curricula considerations, much is now known about keyfactors[12,13,14] for promoting diversity through curriculum design.

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[10] See (Caspersen et al. 2022).

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

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

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

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

Ways to support pupils who may have special needs should be considered at the point of curriculum implementation. Some ways to support pupils are already known[15] 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.[5]

Particularly with respect to gender, some early research has indicated that girls in general tend to be interested in social and future concerns – the purpose and use of technology – whereas boys in general can be interested and focus more on direct creation and use – the devices themselves.[16] Other research[17] has suggested other dimensions: "ingressive" (concerns with aggressive, individualistic, single-track or "device" thinking) and "congressive" (concerns with the collective rather than the individual, bringing things and ideas together). Clearly a "congressive" approach can be beneficial for all, regardless of gender. Thus, it is important to ensure that the human and real-world relevance of curriculum activities is emphasised. Furthermore, engagement with informatics at an early age can promote self-efficacy, which is particularly crucial for girls[18] and can tackle gender stereotyping before prevailing views become entrenched.

Teachers play an essential role in setting up learning environments that engage all pupils naturally as well as choosing gender-sensitive examples and approaches.

From overall broad aims and goals, curriculum implementation 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 3.1, there are other important and general design approaches discussed in Section 3.1 that should be carefully considered.

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. For example, asking pupils to write down the key components of a computer might identify *what is known*, while asking pupils to program a Turtle to turn 90 degrees might identify *what can be done*. Similarly, asking pupils to work together to code a program to dispense water when a

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

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

[17] See (Cheng 2020).

[18] See (Aivaloglou & Hermans 2019).

certain humidity is reached might identify *what can be done with others*, while asking pupils to work with a parent who is trying to measure the growth of a plant over certain time intervals might identify *what can be done for others*.

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. For example, writing a program to enumerate the value of pi to a certain number of decimal places. ***Showing physical outcomes*** can include assessing physical outcomes or artefacts. For example, creating a portable system to measure water temperature at a particular depth. ***Relating group experience and outcomes*** might relate to how teamwork has been organised, how it has operated, and what has resulted. For example, asking each member of a group to list their tasks and actions when creating an electronic version of a board game. ***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. For example, asking a shopkeeper the outcome of a system that pupils developed to identify customer satisfaction.

Core concepts and content are a next stage of curriculum design, to consider the subject content of a curriculum. In the Informatics Reference Framework[19], the subject content is based around a number of core topic areas. 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 creationof learning activities to meet the features chosen, which lead to learning outcomes. Examples of intended outcomes are presented in the Informatics Reference Framework for School.[17]

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 3.2.

The example in Table 3.2 illustrates a recurring learning activity on *data collection and analysis* related to several of the core topic areas, 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 the example in Table 3.2, the curriculum design is interactive and outcomes-based, using elements of an inverted and spiral design where possible. Please note that the forms of learning activity and associated assessments would be done at different times, according to where they arose in the lesson planning activity sequence (in these examples, across a two-year period in each education level).

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[19] See (Caspersen et al. 2022).

Table 3.2: Example learning activities related to intended learning outcomes within a specific subject topic area (data and analysis collection) across a time period for each level of education

	What is known	***What can be done***	***What can be donewith others***	***What can be done for others***
Primary	**At an early stage in the year**	**At a later stage, perhaps a few days or a week later**	**The following year**	**At a later stage that year**
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 weatherstation collectsdata and how they are recorded.*	*Pupils set up a sensor systemto 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	**At an early stage in the year**	**At a later stage, perhaps a few days or a week later**	**The following year**	**At a later stage that year**
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	**At an early stage in the year**	**Perhaps a few days or a week later**	**The following year**	**At a later stage that year**
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.*

What next? Designing an effective informatics curriculum is the challenge we face, doing this in ways that enable teachers to take curriculum outlines and guidance forward when implementing a curriculum in practice. Guidance certainly needs to take context into account but should also accommodate and integrate design principles and needs outlined in this report. How will you take forward these principles to engage all pupils in an effective informatics curriculum?

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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.