

# Considerations for the Design of Computing Curricula

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**Abstract:** This paper originated from discussions about the need for important changes in the curriculum for Computing including two focus group meetings at IFIP conferences over the last two years. The paper examines how recent developments in curriculum, together with insights from curriculum thinking in other subject areas, especially mathematics and science, can inform curriculum design for Computing. The analysis presented in the paper provides insights into the complexity of curriculum design as well as identifying important constraints and considerations for the ongoing development of a vision and framework for a Computing curriculum.

**Keywords:** Curriculum, Computer Science, Informatics, curriculum theory

## 1 Introduction

Recent review of the ICT curriculum in the UK (The Royal Society, 2012) identified a need for major reform that recognises the value of Computer Science as an academic discipline. Similar calls have been made in the United States (Wilson, Sudol, Stephenson, Stehlik, 2010) and throughout Europe (Joint Informatics Europe & ACM Europe Working Group on Informatics Education, 2013). These initiatives emphasise refocusing Computing education to incorporate Computer Science as the underlying subject discipline. A major concern is that the curriculum has become unbalanced with too much focus on basic digital skills at the expense of deeper understanding of concepts. This has led to much debate about what should be included on Computing and/or ICT in the curriculum. In this paper I will examine this debate and consider the role and purpose of the Computing curriculum. In particular I will focus on the theoretical basis for the design of curricula for Computing: how will we decide

the curriculum content and focus? What is its purpose? And what are the implications for the design of the structure and sequencing?

This paper builds on focus group meetings that took place at the IFIP Conference in Manchester and the World Conference on Computers in Education 2013 in Torun, Poland. These meetings highlighted that there are a range of views among professionals working in the area of Computer Science and ICT. A general agreement reached in these meetings was that in order to define a vision or framework, which may help to inform curriculum development, we need to define what is the range and scope of the subject and what are the key ideas and subject matter in the field(s) and at the same time explain why these are important for people to learn. In this way we can move towards a vision and rationale for the curriculum and perhaps a framework. In this paper I am not aiming to synthesise all of the debate from those meetings. Instead I aim to suggest some ways to take forward this debate and of moving towards a vision for future development of the curriculum relating to Computing/ICT. In order to do this I will examine recent debates in curriculum theory generally as well as other subject areas with relevance to Computing and consider possible implications for the Computing curriculum. First I will briefly explain the terminology and background including the debate about the Computing curriculum in the focus group discussions.

## 2 Background and Terminology

The variation in terminology has been a source of much confusion in relation to Computing/ICT. The Royal Society report (2012) provided some useful definitions based on the situation in the UK in 2012 (see Table 1) and these will form the basis for definitions in this paper with some further clarification as explained below.

Table 1: Computing in schools terminology (The Royal Society, 2012, p. 5)

<p><b>Computing</b> The broad subject area; roughly equivalent to what is called ICT in schools and IT in industry, as the term is generally used.</p> <p><b>ICT</b> The school subject defined in the current National Curriculum.</p> <p><b>Computer Science</b> The rigorous academic discipline, encompassing, programming languages, data structures, algorithms, etc.</p>	<p><b>Information Technology</b> The use of computers, in industry, commerce, the arts and elsewhere, including aspects of IT systems architecture, human factors, project management, etc. (Note that this is narrower than the use in industry, which generally encompasses Computer Science as well.)</p> <p><b>Digital literacy</b> The general ability to use computers. This will be written in lower case to emphasize that it is a set of skills rather than a subject in its own right.</p>
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While the school subject in the UK had come to be called ICT, in many other parts of Europe, a scientific discipline, known as Informatics (Joint Informatics Europe & ACM Europe Working Group on Informatics Education, 2013) had continued to be followed in some countries. Informatics is a broader term than Computer Science, for example the Joint Informatics Europe & ACM Europe Working Group on Informatics Education use the term Informatics to “cover the entire set of scientific concepts that make information technology possible” (2013, p. 9). In this paper the terminology shown in Table 2, which is largely based on the Royal Society Report, will be used. Thus the term ICT will be avoided in this paper as its meaning is subject to too much variation in interpretation and Computing will be used to designate the broad subject area.

Table 2: Terminology used in this paper

Information Technology (IT) – The use of computers, in industry, commerce, the arts and elsewhere, including aspects of IT systems architecture, human factors, project management etc. (Note that this is adopted from the Royal Society Report and is the title of courses in the UK at GCSE and A-level)
Computer Science – The rigorous academic discipline, encompassing programming languages, data structures, algorithms, etc.
Computing – The broad subject area. This is now the title for the new curriculum in the UK
Digital literacy – The general ability to use computers

The focus group meetings at the IFIP conferences in Manchester and Torun aimed to debate the issues with a view to moving towards a consensus about a vision for the curriculum and how to develop a framework for the design of a curriculum for Computing/digital literacy. The debate was enthusiastic and quite wide-ranging and suggested that reaching a clear consensus and way forward was likely to be difficult. Table 3 summarises key ideas that arose together with an estimate of the level of consensus amongst the participants. The range of views and lack of consensus indicated in Table 3 as well as in other debates about the curriculum for Computing/digital literacy indicate the extent of the challenge of designing a curriculum framework and suggest a need to identify a possible theoretical basis for curriculum design in this area.

### 3 A theoretical Basis for Curriculum Design

An obvious starting point for a theoretical basis for designing the Computing/digital literacy curriculum is curriculum theory. However curriculum theorists have identified a crisis in their field (Priestley, 2011; Young, 2013). Priestley argued that the crisis is due to new uncertainties which require new approaches to practice and new ways of thinking (Priestley, 2011). This, Priestley argues, is evident in the emergence of new models of national curricula around the world characterised by outcomes sequenced into linear levels and an emerging focus on generic skills (*ibid.*). Curricula have been developed that are a-theoretical and instead aim to meet the needs of learners using a pragmatic approach with inherent contradictions and lack of conceptual clarity (Priestley, Humes, 2010). Young attributes the crisis to the neglect of the role of access to knowledge in current curriculum theory (Young, 2013). Biesta (2014), on the other hand, questions whether knowledge can be viewed in isolation from other considerations such as critical judgement. Biesta argues, based on Dewey's work, that knowledge is a construction in "transaction" (interactions taking place in nature) which means that knowledge is both constructed and real. In Dewey's view as examined by Biesta, in order to get knowledge we need action. Within this view of knowledge, deciding curriculum content is a matter of coordination between individual learners and social factors. Therefore, Biesta argues, when designing curricula, we should proceed pragmatically in a careful and precise way in relation to matters of human concern. Thus significant philosophical differences are evident in curriculum theory.

This crisis is not just a recent phenomenon but rather a series of cycles of reconceptualisations that started in the 1970s (Pacheco, 2012). Curriculum studies and curriculum theory are complex and many factors have been important in recent changes and recent thinking including philosophical and epistemological considerations, internationalisation, and politicisation. The precise nature of the current crisis or cycle is beyond the scope of this paper – see Pacheco (2012) for an overview of the state of the curriculum studies field. What is clear is that there is no one theory of curriculum or curriculum design that is commonly accepted and will provide us with the means of establishing a curriculum vision and framework. What we can take from the various debates about curriculum theory are a series of questions and issues applicable to curriculum design in general which can be examined in relation to current thinking about Computing/digital literacy curricula and specific examples of curricula or curriculum frameworks. Furthermore various constraints on curriculum design have been identified particularly from epistemological considerations (Winch,

2013; Young, 2013) and we might consider how they should constrain curriculum design for Computing/digital literacy.

Table 3: Views that emerged from the WCCE panel discussion (Torun 2013)

<b>Key idea/question about Computing curricula</b>	<b>Level of consensus</b>
Computer Science and digital literacy are complementary – both are needed in the school curriculum	High
Need room for flexibility in interpretation	High
What is the importance of Computer Science for general education? – This is important	High consensus that this question is important
Problems of defining terms	Consensus that terminology is important and difficult
We need to develop aware citizens – not necessarily creators but more than consumers	Controversial
Teaching children to be aware, not necessarily how to create from scratch	Controversial
Current trend is a grass roots movement that appears to have joined forces and coordinated. At the heart of it is an understanding that Computing is essential for all children but also a need for opportunities for career paths and citizenship	Fairly high
A set of concepts based on Computer Science should be defined as a basis for the curriculum – some concepts have a long shelflife whereas others are short-lived	Fairly high
Computer Science is for everyone	Controversial
What are the good practices that are working?	Controversy over whether this is an important question or not?
Towards a curriculum framework: When – from the beginning What – clear examples How – basic principles Who – concerns with teacher training	The key principles of what needs to be decided or agreed.

The questions include: What is learners' entitlement? What is the nature of knowledge in relation to the curriculum? What is the relationship between theory and practice? How detailed should curriculum specifications be?

## **4 Learners' Entitlement to Knowledge**

It is self-evidently obvious that curriculum design should pay attention to learners' entitlement. For Young (2013) resolution to the crisis in curriculum theory should be through a "knowledge based" approach which starts from the learner's entitlement to knowledge. He argues that there are two important models for curriculum design which both need to be harnessed. The first model, which inherits a view of the curriculum as a source of the sacred, puts trust in knowledge and in teachers as pedagogic authorities whereas the second put its trust in the emancipatory capacities of learners (ibid). According to Young, curriculum theory must take, from the sacred tradition, both: 1) the idea of a store of knowledge and 2) human values of inwardness and dedication that shape and are associated with disciplined study and enquiry. At the same time, according to Young, in order to harness the emancipatory capacities of learners, the curriculum should take them beyond their own experience so curriculum design should start from the learner's entitlement to knowledge. Thus the goal of the curriculum becomes to define its content in a world in which the entitlement to knowledge is the goal. In this endeavour "powerful knowledge" is key, defined as specialised discipline-based knowledge which is different from the experience-based knowledge that pupils bring to school (Young, 2013). The next step in this paper is to examine epistemological considerations in more depth in relation to knowledge in curricula.

## **5 The Nature of Knowledge**

A philosophical issue influencing both curriculum change and pedagogy is the changing nature of knowledge in the knowledge society in which a view of knowledge as a fixed body is giving way to something with verb-like characteristics which is rapidly changing and developing through networked interactions (see for example Hipkins, Reid, Bull, 2010 for a review of recent thinking). In the knowledge society the need for people to be involved in continual knowledge creation through interaction in social cultural settings is in conflict with educational processes which build young people's knowledge through a predetermined sequence of learning (Bauman, 2005). These knowledge creating processes are undeniably important in most areas of endeavour but the extent to which knowledge creation should determine the curriculum in primary and secondary schools is a matter of debate. The concept of powerful knowledge (Young, 2013) presents a way of thinking about knowledge where, even in this changing scene, some types of knowledge are more important for

curriculum design than others. Young's explanation of "powerful knowledge" resides in the knowledge associated with academic subjects which he argues is specialised and differentiated by the boundaries between school and everyday knowledge. Clearly, as Young argues, this knowledge is not fixed nor is it equally easily identifiable across all subjects but in each discipline there are people committed to creating and evaluating some kind of knowledge base. Whether or not we believe that powerful knowledge should be the key ingredient of a Computing/digital literacy curriculum, reviewing what such powerful knowledge might be will at least give us an insight into how such thinking plays out in our discipline.

Epistemologists generally recognise three kinds of knowledge: propositional knowledge, know-how and knowledge by acquaintance (Winch, 2013). In examining how these forms of knowledge are relevant for curriculum design, Winch utilises Paul Hirst's characterisation of forms of knowledge into propositional knowledge, conceptual structures and methods of investigation (Winch, 2013). In this characterisation, forms of knowledge can be distinguished through variation across all three of these dimensions. According to Winch a key insight of the Hirstian classification is the close relationship between propositional and practical knowledge as well as the close inter-dependence of propositions. These propositions, through the mediation of concepts, particular to the subject, as well as more general concepts, form the basis of understanding through the mastery of inferential relationships. Thus attention focuses on 1) learning as concept formation and 2) on practical procedures for managing knowledge. From this view curriculum design is about the management of growth of expertise within a subject which recognises different kinds of knowledge and their interrelationships. Winch argues that gaining a coherent view of this "epistemic ascent" within a subject is a key element in curriculum design. Therefore a major issue in curriculum design is to obtain sound grounds for the construction of schemata of epistemic ascent that are at least conceptually and normatively sustainable even if they are not yet empirically ratified.

The discipline of Computer Science encompasses foundational principles, widely applicable ideas and concepts as well as techniques and methods for solving problems and advancing knowledge as well as a distinct way of thinking and working (The Royal Society, 2012). Thus according to Young's (2013) definition Computer Science provides all or part of a powerful knowledge base which would be learners' entitlement. In this description provided by the Royal Society (2012) the three types of knowledge described by Winch (2013) are evident as is the importance of concepts and of practical procedures for ma-

naging knowledge. Key concepts identified by the Royal Society Report were programs, algorithms, data structures, architecture and communication (The Royal Society, 2012). The Joint Informatics Europe & ACM Europe Working Group identified similar concepts but theirs, they explained, were just examples from a much longer list. Therefore there remains a task, perhaps for IFIP TC3, to consider a complete high-level list of concepts for the curriculum. The techniques and methods that the Royal Society Report identified were modeling, decomposition, generalising with algorithms or data, designing, writing, testing, explaining and debugging programs (The Royal Society, 2012). Again the Joint Informatics Europe & ACM Europe Working Group identified similar techniques and methods but they also identified the importance of various intellectual practices such as tolerance for ambiguity (Joint Informatics Europe & ACM Europe Working Group on Informatics Education, 2013). Thus we are seeing consensus emerging from these working groups about the key concepts and techniques of the discipline although perhaps not yet agreement about the importance of more general intellectual practices. However, Computing as a practical subject, as well as theoretical raises other more complex issues concerning the relationship between theory and practice (Schwab, 1971; Winch, 2013) that will be discussed in the next section.

## **6 The Relationship between Theory and Practice**

As Schwab (Schwab, 1971) argued, the difficulties in reconciling theory and practice within the curriculum are associated with the fundamental differences between them in that practical is concrete and particular whereas theory is general and economic in its specification. Thus in dealing with a practical problem in any discipline it is necessary to take account of a range of conditions which may not be addressed by the theory. Arguably, in learning Computing, the practical is more critical than in some other subjects with practical elements such as science where the practicals, at least at the level of primary and secondary science, are predominantly for the purposes of motivation and pedagogy rather than for developing the practical techniques per se (Abrahams, Reiss, 2012). In Computing, it is not only Computing professionals who need to develop practical skills in Computing, but skills and processes such as programming and computational thinking are needed both for personal productivity and across a range of other professions. Thus practical work is essential and may serve a variety of purposes.

Schwab's solution (Schwab, 1971) to the dilemma of the complex relationship between theory and practice is to employ a cyclical process whose



purpose is to link theory and practice by mastering two or more theoretical viewpoints and their practical application, one at a time avoiding comparisons, and then once they have been mastered on their own terms to compare and contrast them. Each cycle contains two stages: the first of which is to master the theoretical viewpoint and the second to apply it to a series of cases. In brief, Schwab's rationale for this approach is the need for understanding plurality and the tendency for students, if faced with a new viewpoint before they have assimilated the first, to assimilate the new doctrine only in terms of the first. It is beyond the scope of this paper to develop this idea in depth in relation to Computer Science but I suggest that it has implications for the learning of programming, in particular the range of programming paradigms to be included in the curriculum as well as the mastery of specific programming languages. This approach has implications both for the range of content of the curriculum and for its structure and organisation.

## **7 Learners' Entitlement – A Curriculum for all**

Young's argument, outlined above, is that the curriculum question: what knowledge? is primarily an epistemological one about what should constitute students' entitlement, together with identification of the epistemological constraints on structuring knowledge from the discipline into sequences suitable for different developmental stages (Young, 2013).

So far I have discussed the nature of knowledge and the importance of practical as well as theoretical knowledge. Learners' entitlement implies entitlement for all and therefore we need to consider a more controversial question: do *all* students need to understand the powerful knowledge in Computing that we have begun to identify? Such a question is rarely asked of other major discipline areas such as maths, English, science, history etc. because in most countries their place in the curriculum is assumed. Therefore the discussion of the curriculum in these traditional subjects focuses on the extent and range of the subject and the rationale. However Computing being a young discipline, its very existence in a curriculum needs to be justified carefully. There are many who have argued that the best basis for studying Computing at higher levels is a grounding in mathematics and natural science and that therefore strong foundations in Computer Science are not necessary in compulsory schooling. Arguments against such a view and in favour of Computing being part of the compulsory curriculum are varied and include the need for careful and systematic development of the principles and processes of Computer Science in order to avoid the ad hoc development of bad habits as well as the need to

support creativity and problem solving more generally. There are three particularly compelling arguments for the Computing curriculum in compulsory education. First if learners are never introduced to Computing as a disciplinary area and to the knowledgebase and approaches that Computing academics and professionals use then they will not be able to determine whether this is for them. This therefore is an entitlement issue. Second, as many in the profession have argued, programming is difficult and it takes many years to learn to program. While programming is only one element of Computer Science, it is an essential element and it is inconceivable that an introductory course in Computer Science would not contain programming. Furthermore, while Computing professionals do not necessarily do the programming themselves, they need to understand essentials of programming in order to undertake a career in Computing. There is a view among Computer Science educators that coming to programming late in students' development is disadvantageous and that if they were to learn some of the techniques, approaches and thinking involved in programming at an earlier stage more of them would be successful. This therefore is both an entitlement issue for individuals looking towards a fulfilling, creative and potentially lucrative career as well as of concern to countries in terms of their economic performance and prosperity. The third argument is based on the ubiquitousness of Computing: since so much of our lives is dependent upon Computing we need to develop the understanding and skills of Computing necessary to participate in society. Both the Royal Society Report (2012) and the Joint Informatics Europe & ACM Europe Working Group (2013) emphasise individual entitlement, effects on economic prosperity and social aspects in their arguments for redeveloping Computer Science education.

The first two arguments outlined above are primarily based on the vocational rationale of enabling individuals to fulfil their ambitions of careers in Computing if they wish and also providing the workforce that will support the country's economy and its place in the world. While such justifications are often used and are sufficient to support the existence of a Computing curriculum there are many other roles which this curriculum could encompass including: the development of computational thinking as a basic literacy that is important to everyone in everyday life (Wing, 2006); developing the ability to solve problems with computers which is needed by a wide range of professionals; understanding the advantages and limitations of computer technology in order to make informed decisions about technology futures. In the light of this range of different roles that the Computing curriculum could support it is important to consider whether or not a broader rationale is achievable or would result in too many conflicting priorities. Linked to this question is the place of

digital literacy and whether or not a Computing curriculum should incorporate all or some of the elements of digital literacy or whether digital literacy is an entirely cross curricular element. If we take Mioduser et al.'s explanation of the literacies associated with technologies as both affording and demanding their evolution then there are seven such literacies: multimodal information processing, navigating the infospace, interpersonal communication, visual literacy, hyper-literacy (hyperacy), personal information management (PIM), and coping with complexity (Mioduser, Nachmias, Forkosh-Baruch, 2008). Even a brief consideration of some of these literacies suggests that they require theoretical understanding in addition to practical skills. Furthermore while this theoretical understanding is broader than Computing there are some elements of understanding of Computing that would support most of these.

Other disciplinary areas have addressed these issues of how to deal with multiple, potentially conflicting, rationales, notably science education which, in Europe at least, has recently emphasised active, participatory approaches and a focus on contemporary societal issues in the earlier stages of compulsory education moving towards consideration of the nature of science and scientific method in upper secondary education (Eurydice, 2011). In maths education, where applied mathematics shares some characteristics with Computing, a debate has started about the needs of “constructors”, “operators” and “consumers” (Skovsmose, 2004). We can see parallels here with the debate about the Computing curriculum in which the call for enabling students to be technology designers and creators not just consumers (The Royal Society, 2012) has echoed across recent debates in Computer Science education. Skovsmose's classification of those who practice mathematics is based primarily on an economic and vocational perspective. Thus constructors are those who maintain and further develop knowledge and techniques incorporating mathematics across a range of disciplinary areas; operators use mathematics only as part of the tools and instruments which they operate and consumers are those who only use mathematics in their daily life in order to interpret information such as tax returns, discounts etc. For Skovsmose the implication of the broadening of mathematics education, so that it can no longer rely for its position in the curriculum entirely on its intrinsic value but rather depends on its role as preparation for a range of social practices, is the need to live with uncertainty. In such uncertainty there is no foundation from which to build a strategy and instead it is necessary to live with uncertainty. From this perspective the only option is Biesta's (2014) pragmatic approach of proceeding thoughtfully with careful attention to matters of human concern. A next step is to examine constraints which might guide such a process.

## 8 Constraints

Important epistemological constraints on curriculum design were identified by Winch's (2013) analysis that focused on expertise and the idea that both subject knowledge and the growth of expertise in practical subjects require "epistemic ascent" through mastery of different kinds of practical ability. Moreover Winch argues the need to explore the constraints that the conceptual structure of the subject might impose on pedagogically and cognitively coherent schemata of epistemic ascent and then explore the implications of such constraints within conceptualisations of the subject. The constraints identified by Winch include three interrelated issues. First, it is necessary early in a curriculum (e.g. at primary level) to introduce all three major types of knowledge. This is because knowledge of individual propositions implies some understanding of the concepts that such propositions express and this in turn implies a significant ability to understand and make inferences within the subject. This is Knowing How to do something. Second there is a need for a structured approach to progression in learning the basic facts and central concepts of the subject because knowledge is systematic in terms of 1) classification of its various conceptual elements; 2) the relationships between the elements and 3) the procedures required to gain and validate knowledge. Third the kind of knowledge required to expand and manage subject matter requires a profound understanding of the subject including all of these interacting knowledge types. This therefore is not accessible to school students but comes in more advanced studies beyond school. The fourth constraint follows from the third and requires that the relationship between the ways in which pupils learn by simulating procedures for the acquisition of knowledge in their learning and the actual processes of expansion of disciplinary knowledge should be clarified. For example, project work in Computing often involves the systems development life cycle. Winch argues that simulating such procedures may be pedagogically important in developing acquaintance with the knowledge set of the subject as well as building understanding of techniques used in knowledge management. However these simulations should not be seen as simplified versions of expert practice as that might propagate an illusion that high-level design and planning activities are generic and can be used free of the reality of the skills and materials that are needed to execute the plan. Instead it should be recognised that such expertise requires extensive knowledge and is therefore only possible in higher level courses that build upon previous structured development.

## **9 How detailed should Curriculum Specification be?**

The level of detail for the curriculum specification depends on its purpose and the view of knowledge which it embeds. Current curricular specifications are very variable, ranging from the 2-page spread of the UK National Curriculum for Computing to many pages of detailed specification. Some recent specifications have featured structured sequences of outcomes and a focus on generic skills or capacities rather than detailed specification of knowledge (Priestley, 2011). The use of these structured sequences, often described as competences, raises two important issues for curriculum design. First the understanding of competences varies in different countries (Gordon et al., 2009): for some competences are overall capacities in relation to a broad occupational field. Typically these competence frameworks incorporate a range of knowledge and skills as well as personal qualities. In other countries, such as the UK, competencies are generally defined as the ability to perform prescribed tasks to a certain standard. While these different definitions are sometimes distinguished by the use of the terms competencies and competences with and without an ‘i’, these distinctions are not universally adhered to. The second issue concerns how competences are derived. The two possibilities are: 1) by a rational analysis of the subject domain or area of expertise and 2) from the vocational demands of an area of work. Both are potentially problematic when changes are rapid as with Computing, where detailed specification may lead to stagnation unless the curriculum is kept under review.

## **10 Discussion and Conclusion**

The brief journey into curriculum theory discussed in this paper has highlighted issues contributing to complexity as well as tensions and constraints in relation to designing a Computing curriculum. This explains, at least in part, the reasons for the challenges identified in previous focus group discussions. The lessons from curriculum theory and from experiences of curriculum design in other subjects suggest that we need to live with uncertainty and to accept the need for a dynamic and continually renegotiated curriculum. However there are epistemological considerations and constraints which can guide curriculum design (Winch, 2013; Young, 2013) even if it is necessary to take a primarily pragmatic approach as advised by Biesta (2014). A key consideration obviously should be learners’ entitlement (Young, 2013) and identifying the knowledge that might constitute at least part of this entitlement must be an important part of the endeavours of those in the discipline that understand the current sta-

te of disciplinary knowledge. While the identification of such knowledge is no doubt made more complex by the changing nature of knowledge brought about by the knowledge society, it is clear that in computer science, some knowledge is sufficiently stable to be classified as powerful knowledge. At the same time the changing nature of knowledge and ways in which expertise can be developed are important issues in the 21st century which learners need to gain access to. In a previous paper, primarily focused on pedagogy (Webb, 2012), I argued that pedagogy needs a balance between learner-led and learning-led approaches which incorporate respectively development of specific expertise in limited areas focusing on learners interests together with curriculum-based learning led by specialist teachers that provides entitlement to knowledge.

Recent curriculum design for computing suggests that a consensus is emerging with respect to powerful knowledge which includes the key concepts of the discipline of computer science and of the techniques and methods. There is not yet clear agreement about the importance of various intellectual practices such as tolerance for ambiguity, which are broader than computing. Based on the analysis presented in this paper I suggest that the ongoing task of defining a vision and framework for Computing curricula requires the following inter-related and iterative activities:

- Continuing to identify and developing a consensus about key conceptual structures, propositional knowledge and methods.
- Deciding which knowledge elements are important for the varying roles of curricular identified as:
  - learners' entitlement in relation to future careers/employment;
  - personal productivity and the use of technologies for learning, social participation and leisure;
  - economic prosperity and future development at both country and global levels;
  - participation as informed citizens in decisions about technology futures e.g. in the role of robots and development of robotics.
- Deciding sequences/schemata for mastering knowledge that are conceptually and normatively sustainable bearing in mind the epistemological constraints identified in this paper. This process includes deciding on the level of detail that might be appropriate given the advantages and disadvantages of over specification discussed earlier.
- Identifying developmental constraints and pedagogical considerations including motivational aspects such as creativity and context.

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Monique Grandbastien, France; Alain Senteni, UAE and Quebec; Mary Webb, England; Nicholas Reynolds, Australia; Andrej Brodnik, Slovenia; Ivan Kalas, Slovak Republic; Bruria Haberman Israel; Harriet Taylor, USA



## Biography



**Mary Webb** is Senior Lecturer in Information Technology in Education at King's College London and Chair of IFIP Working Group 3.3 on Research. Mary has developed and researched computing and the use of digital technologies in learning and teaching since computers first appeared in schools. She has taught Computer Science in secondary schools and runs a PGCE Programme for new Computer Science teachers.

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