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Pedagogical Reasoning: Issues and Solutions for the Teaching and Learning of ICT in Secondary Schools

MARY E. WEBB
Department of Education and Professional Studies, King's College London, Franklin–Wilkins Building, Waterloo Bridge Wing, Waterloo Road, London SE1 9NN, UK
E-mail: mary.webb@kcl.ac.uk

Abstract

Confusion has developed over the role of ICT in schools as a result of conflicting messages from government-led initiatives and changes in the technology. Amidst the ongoing debate about the purpose and rational for ICT in schools a subject has evolved called ICT (Information and Communications Technology), IT or Informatics. Whilst the nature and content of the subject has been fairly clearly defined with significant agreement between specifications from a range of countries, the pedagogy is still unclear. The analysis that I present here of the pedagogical reasoning process as it applies to ICT teachers who are implementing the ICT curriculum in England reveals the basis of the difficulties in teaching ICT and leads to the identification of issues for the development and integration of theories and practices for learning and teaching ICT. These issues are discussed in relation to developments in pedagogy in other curriculum areas, notably science, and an agenda for developing a pedagogy for ICT is proposed.

Keywords: ICT, information and communications technology, pedagogy, secondary schools, pedagogical content knowledge

Introduction

The importance of ICT (Information and Communications Technology) in the school curriculum has been emphasised recently by government initiatives involving increasing investment in ICT facilities related to learning and teaching with ICT. Since 1998 new programmes have been established which account for new funding of over £1.2bn towards the National Grid for Learning (NGfL) (DfEE, 1997). These developments are intended to improve ICT skills as well as to enhance teaching and learning (Prime Minister, 2000). In England the term ICT is used to describe both the study of and the use of computers and other technologies that are used for communications and Information Systems (DfEE, 1999). In other countries the terms IT or Informatics are used to describe the study of such systems and indeed previously in the UK these alternative descriptors have been used (ACITT, 1998; DfE, 1995).

The development of the NGfL was a response to the Stevenson report (1997) that identified inadequate hardware, little software related to the curriculum, and variable teachers' skills and attitudes as major factors limiting widespread appropriate use of ICT in schools. However, more recent evidence of standards of teaching and learning in ICT (Ofsted, 2001) whilst showing signs of improvement still reveal significant shortcomings. These deficiencies, together with the perceived importance of developing ICT knowledge and skills has led to calls for the elucidation of a pedagogy for ICT (e.g., Johnson and McLean, 2001).

In this paper, I will consider the issues concerning teaching the subject of ICT/Informatics by exploring the pedagogical reasoning process based on Shulman's (1987) description. I will then suggest ways forward in formulating a pedagogy for learning ICT by drawing on research in ICT and learning, and from teaching and learning in other subject areas.

First, I will try to clarify the position of ICT in the school curriculum where three separate aspects can be identified: learning ICT (the subject); using ICT as a tool for learning; learning through ICT. ICT as a subject in the curriculum in England is specified by GCSE and A-level syllabuses and by the National Curriculum (DfEE, 1999). The use of ICT, particularly computers and network communication, to support teaching and learning includes a wide range of applications of ICT as a tool, e.g., using a word processor to enable redrafting of an essay; running a simulation to test a prediction in science; developing cross-cultural understanding through computer conferencing, etc. "Learning through ICT" is used to describe situations where the ICT facility becomes the whole learning environment by providing learning materials and acting as assessor and tutor. Such situations are typified by tutoring systems and Integrated Learning Systems. Most of these offer very limited opportunities for students to learn the knowledge, skills and processes of ICT and therefore they will not be considered in this paper. I will focus on "learning ICT" and also draw on some research findings related to "using ICT" in the curriculum.

There are of course links between these two aspects and there are different views, within the teaching profession, of their importance and interrelationships (e.g., Selwood and Jenkinson, 1995; Van Weert, 1995a). Is it appropriate, for example, to draw parallels between the English curriculum and the development and use of literacy through teaching and learning of other subjects? Or are the skills, knowledge and processes required to use ICT effectively so basic and straightforward that they can be acquired or taught while using ICT to learn other subjects (Doyle, 1995; Wood, 2001)? This dichotomy characterises the dimensions of a debate that has taken place in schools and advisory services in England over the last twenty years about whether ICT capability (knowledge, skills and processes), particularly at Key Stage 3 (age 11–14) should be developed through teaching ICT as a separate subject or through using ICT in an integrated way across the curriculum.

Government initiatives over 20 years have embodied and created conceptual confusion about the role of ICT in schools (Watson, 1996). The following quote from a recent article in the journal of ACITT, the association of ICT in education, in the UK (Wood, 2001) gives some indication of the nature of the debate among teachers and advisers and the strength of feeling that confusion over the position of ICT is generating:

> "Detractors argue that technology is going to become transparent, there will be so much technology in society that children will just use it without thinking. Far from being an argument that negates the need to teach ICT, for me it is the strongest argument of the necessity to help children become aware and appreciative of the depth behind all these easily won skills. The more the technology is hidden, the more it needs revealing and explaining.

> Biology teachers do not teach children how to brush their teeth, they teach them what happens if they don't, and why. Some day, ICT teachers will be revered for their knowledge of the underlying technological principles in this, the information age, rather than be seen as unnecessary trainers for increasingly intuitive technology." (Wood, 2001, p. 10)

This confusion is not restricted to the UK, and may at least in part be due to perceptions of the changing nature of technology. Surveys including both developed and developing countries reveal a variety of rationales for using computers in schools (Hawkridge, 1990; Van Weert, 1995). A matrix produced to help schools determine the stage of development (IFIP, 2000) suggests that ICT evolves from being a separate subject, through integration, towards a transforming role in which ICT is accepted as a pedagogical agent in itself. In this process a suggestion that ICT as a subject no longer needs to be taught can be inferred, e.g.:

> "Up till now ICT has been taught as a separate subject area. To move to the next phase (transforming), the school chooses to implement an ICT-curriculum that increases the use of ICT in various subject areas with specific tools and software." (Unesco/IFIP, 2000)

While the debate in schools and advisory services continues, the need for more ICT professionals in the workforce (Button *et al.*, 2000) together with reports of the failure of schools to develop ICT knowledge and skills adequately (Stevenson, 1997; Ofsted, 2001) has led to the promotion of a model in which ICT knowledge skills and processes are acquired through specialist ICT lessons and then further developed through their use in other subjects. This model is exemplified by the QCA scheme of work at Key Stage 3 (QCA, 2000).

There is a high level of agreement in the nature and content of ICT/Informatics/ Computing courses specified for secondary-age students in a range of different countries (e.g., DfEE, 1999; QCA, 2000; Hubwieser and Friedrich, 1997; Proulx, 1995; Van Weert, 1997). However, these specifications are restricted to *what* is to be taught and make few suggestions as to what pedagogical skills teachers need to teach these courses.

A first step in defining a pedagogy for the teaching and learning of ICT is to explore the nature of pedagogy and its relationship with others aspects of teaching and learning. This leads to a consideration of processes involved in pedagogical reasoning.

Pedagogical reasoning

Alexander (1992) identifies teaching methods and pupil organisation as the two facets of pedagogy. These are included in Alexander's conceptual framework for educational practice (Figure 1) where pedagogy is one of seven interrelated aspects of educational practice. This implies that a pedagogy of ICT should be elucidated within a broad framework of educational practice. A further point to note from the framework is that what can be observed in the classroom is only part of educational practice. Thus, illuminating good practice in

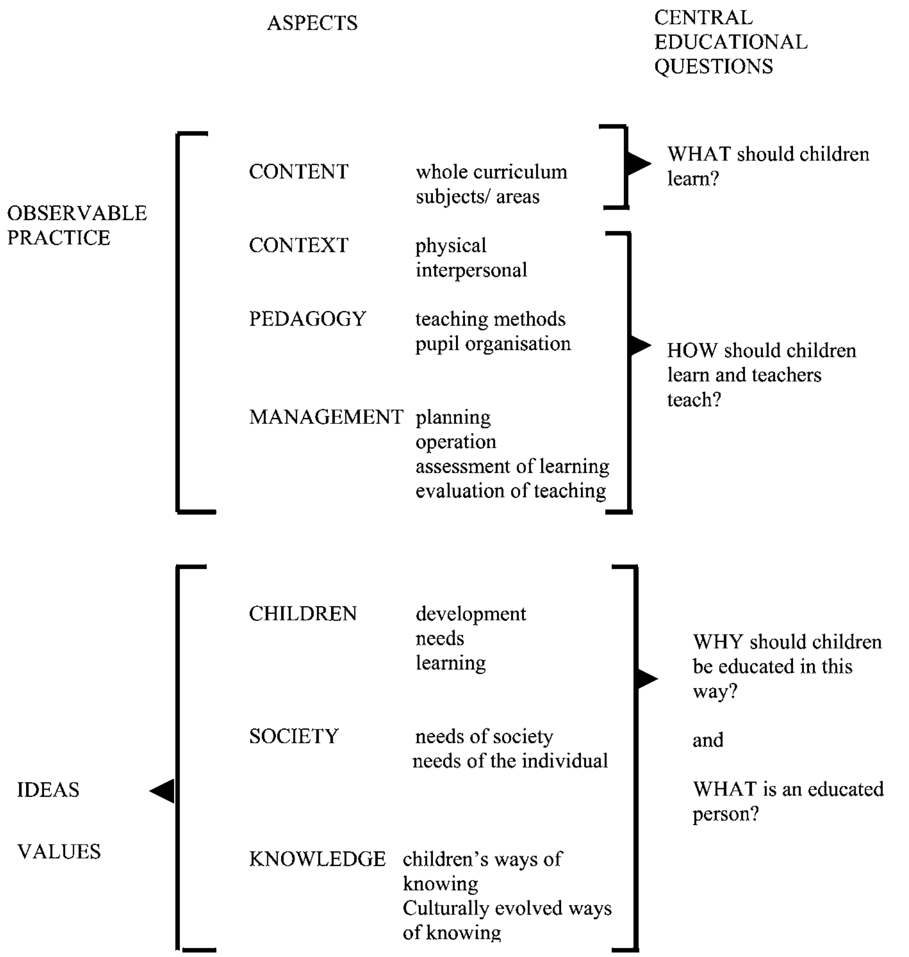

Figure 1. Educational practice: a conceptual framework (Alexander, 1991, p. 84).

the teaching and learning of ICT will require examining teachers' ideas, values, beliefs, and the thinking that leads to observable elements in practice.

Alexander describes the dimensions of his framework as a minimum list rather than a fully comprehensive framework. Shulman's (1987) model of pedagogical reasoning, which I shall discuss later, provides a more detailed description of educational processes that I think can provide a basis for examining the range of issues and problems associated with teaching and learning ICT. Shulman focuses on knowledge rather than ideas and beliefs. Moreover, there is evidence that teachers' ideas, beliefs and values may also influence practice (Fang, 1996; Moseley *et al.*, 1999). Therefore, both facets need to be considered. According to Shulman, teachers' knowledge bases include the following categories of knowledge:

- content knowledge;
- general pedagogical knowledge (knowledge related to general teaching issues, e.g., teaching approaches, classroom management);
- curriculum knowledge (knowledge about the "tools of the trade": schemes of work, resources, etc.);
- pedagogical content knowledge: "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8);
- knowledge of learners and their characteristics;
- knowledge of educational contexts: groups, classes, school and wider community;
- knowledge of educational ends, purpose and values and their philosophical and historical grounds.

This list matches many of the elements in Alexander's list of aspects of educational practice and it includes, and further characterises, much of the knowledge that would be needed to inform those aspects.

Alexander (1992) suggests that in the UK we have focussed on content rather than pedagogy and he argues that content and pedagogy are indissolubly linked. In order to explore this link I will examine Shulman's (1987) model of pedagogical reasoning that focuses on the processes involved in teaching including the transformation of knowledge so that it can be taught. During this cycle of processes, pedagogical content knowledge is used and generated. Other researchers have adopted the term pedagogical content knowledge and defined it for particular subjects, for example Linn and Hsi (2000) state that

> "Pedagogical content knowledge refers to knowledge about a topic that enables improved teaching of that discipline. In science such knowledge involves an understanding of the ideas students bring to class, the context in which students apply their science knowledge, and the multiple models of the same topic used by students and experts in the various contexts of application." (p. 337)

I have represented the main points of Shulman's model in Figure 2 and also added the aspects of ideas, beliefs and values, suggested by Alexander, because the processes will be informed not just by knowledge but by ideas, values and beliefs that teachers use to prioritise and select from their knowledge-base to justify their decisions. For example, a teacher may know a range of theories concerning how children learn through collaboration and exploration but may believe that on Friday afternoon Class 9P will only learn within a tightly managed classroom setting. In some situations teachers may use their beliefs to filter their knowledge-bases at the start so that during the processes of pedagogical reasoning they are only drawing on a limited subset of the knowledge-base.

A crucial feature of this model is the process of transformation of knowledge which Shulman discusses in detail and I have represented in Figure 3. This process of transformation, according to Shulman, occurs not only prior to the instructional process, as shown in Figure 2, but also throughout instruction and during evaluation. I will describe the processes in the model and illustrate them with reference to the teaching and learning of ICT. At the same time I will identify aspects that may be making the processes particularly difficult for ICT teachers.

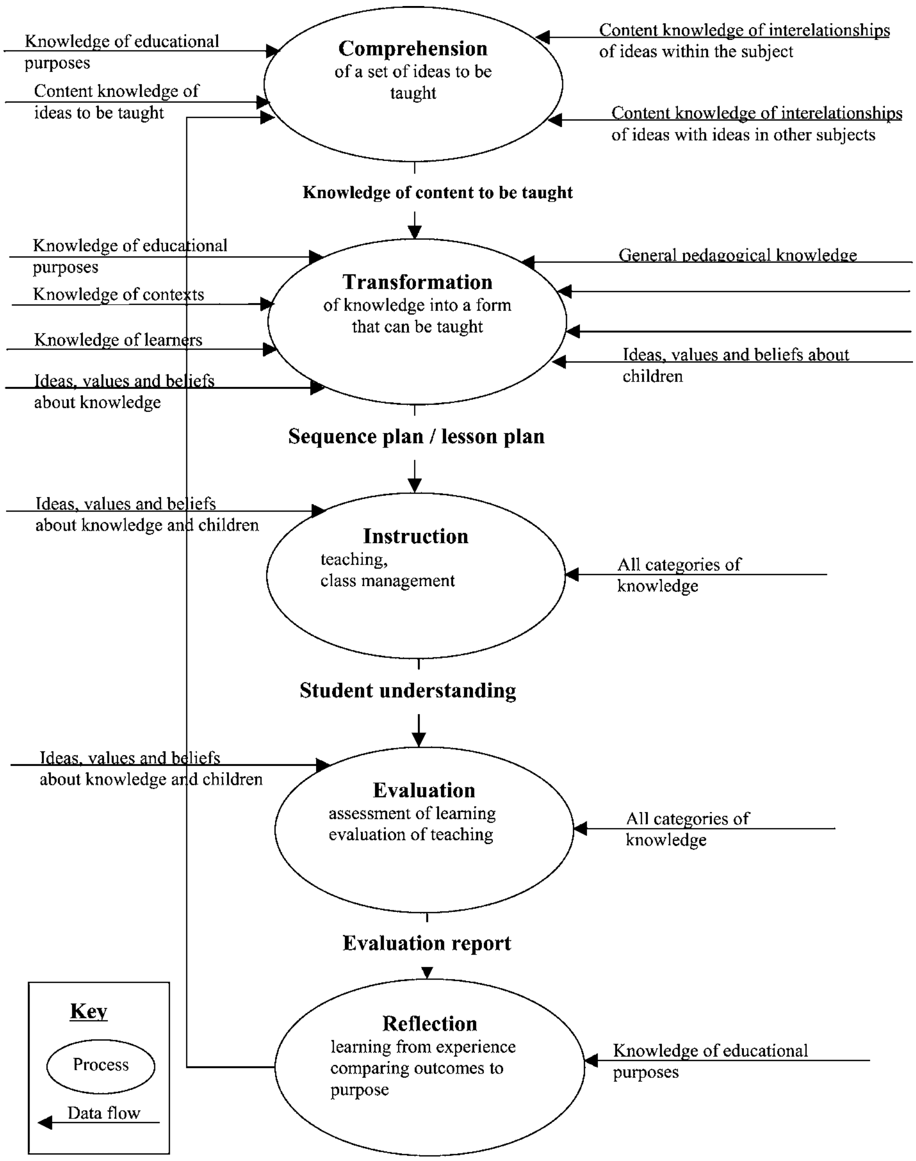

Figure 2. Model of pedagogical reasoning (based on Shulman, 1987).

Comprehension

Comprehension involves examining the content to be taught and considering its interrelationships with other content both within the subject and with that in other subject areas. Shulman suggests that there is usually a text as the starting point. However, in the UK

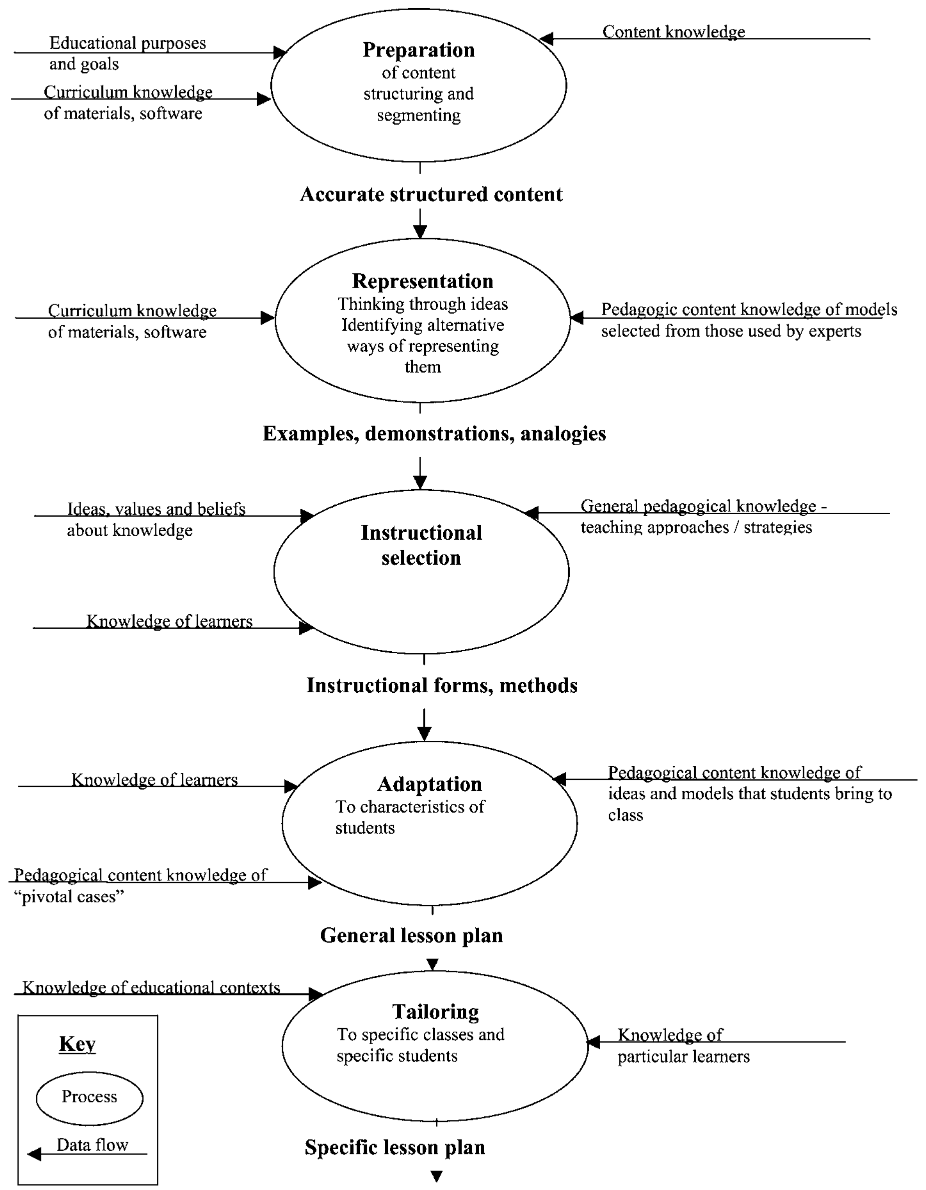

Figure 3. Transformation.

the practice of having set texts is not common, especially below Key Stage 4 (14–16), and certainly ICT teachers generally start from a programme of study in the National Curriculum, or a syllabus, or perhaps a scheme of work. GCSE and A-level ICT syllabuses in general are reasonably precise about the content to be taught but an examination of the

National Curriculum reveals that its poor specification may be contributing to the demise of teaching and learning with ICT. Crawford (1999) examined the 1995 National Curriculum and commented that the requirements of the ICT National Curriculum were "relatively vague compared with those for other subjects" (p. 51). The current National Curriculum specification (DfEE, 1999) still exhibits this characteristic and has become even less specific by changing the names of the strands from names that imply ICT-specific meanings such as "handling information" and "modelling and control" to vague generic titles such as "finding things out" and "making things happen". When examined in more detail the ICT National Curriculum focuses almost exclusively on skills and processes rather than knowledge. For example, in the ICT level description at level 8 each statement is about being able to undertake a skill or process, and although some of these require knowledge and understanding this is not specified. For example:

> "Pupils independently select appropriate information sources and ICT tools for specific tasks, taking into account ease of use and suitability."

This requires understanding of processes (in schools, business, industry or society) that make use of information and how computer systems facilitate these processes, but this is not made clear. In contrast the level 8 description for the Science Curriculum includes statements that specify the need for knowledge and understanding, e.g.:

> "Pupils demonstrate an extensive knowledge and understanding of life processes and living things drawn from the Key Stage 3 programme of study by describing and explaining how biological systems function. They relate the cellular structure of organs to the associated life processes [for example, the absorption of food in the digestive system, gas exchange in the lungs]."

It may be argued that the nature of science with its large body of scientific knowledge and understanding leads to a science curriculum with a more even balance between scientific knowledge and understanding on the one hand and scientific skills and processes on the other whereas ICT is all about solving problems. However the design and technology curriculum, which shares an emphasis on problem solving and the design process with the ICT curriculum, also specifies the need for knowledge and understanding, for example, at level 8:

> "Pupils use a range of strategies to develop appropriate ideas, responding to information they have identified. When planning, they make decisions on materials and techniques based on their understanding of the physical properties and working characteristics of materials."

A further problem with the comprehension process for ICT teachers is that many may have inadequate content knowledge because they lack specific training to teach ICT and may lack qualifications in ICT at degree level (Preston *et al.*, 2000). People who are self-taught in ICT have usually acquired skills in using software packages for their own personal needs, but are less likely to have studied the knowledge and processes required to develop more complex systems in a range of organisations. It is these processes that form the basis of the coursework that typically forms 60% of the assessment of a GCSE ICT course.

Students are expected to document the analysis, design, implementation and evaluation of their systems. A brilliant implementation without evidence of other elements of the process is only eligible for a very small percentage of marks. The educational purpose here is to generate an understanding of the nature of development of ICT systems (the systems life cycle) by ICT professionals, and to learn the skills and processes involved for relatively simple problems that model tasks that the professionals perform. The “systems life cycle” is a key process underpinning the content in ICT syllabuses, so comprehension of its nature and application in a range of real-world contexts is crucial for ICT teachers. A range of knowledge of methodologies, software capabilities, hardware features and the role of ICT in organisations is needed to inform the use and understanding of the systems life cycle.

Once they have a clear idea of content knowledge to be taught, teachers need to consider how it relates to other areas of content knowledge. This is no more onerous for ICT teachers than for those of other subjects but the interrelationships across subjects is more demanding for ICT teachers. Depending on how ICT is organised in a school, the teacher may be expected to plan to teach this content in conjunction with a block of content from another subject area. For example one of my trainee teachers, who is an ICT specialist with no particular knowledge of Geography, was asked to plan and teach a unit of work for Year 9 on the standard of living in Brazil in order to develop Geographical understanding and at the same time develop the ICT skills and knowledge needed to make effective use of information sources such as the Internet. Such practice has been common in primary schools, but in secondary schools it is unusual except in relation to ICT and it is of course more difficult to achieve at secondary level because the content of both the ICT and the other subject is at a more complex level. In this particular case the trainee teacher made a very good job of this project and liased effectively with the Geography Department so that the planning process reflected the needs of both subject areas. Nevertheless the planning process for this example requires a much greater range of professional and pedagogical skills than that required to plan a unit of work within a specific subject area, and it illustrates the additional difficulty that many ICT teachers face compared with those of other subjects.

Transformation

Following comprehension the teacher must transform ideas so that they can be learnt by the students. This process has been broken down into several steps, but Shulman recognises that it is not always sequential.

Preparation

During the preparation process the teacher might examine, for example, a section of a GCSE syllabus and consider exactly what are the key concepts and skills to be taught. Teachers often make their own notes focusing particularly on the level of detail required, and selecting material from their own knowledge at degree level and textbooks.

Representation

The key to the representation process is in thinking of a range of ways that the ideas and skills may be made accessible to the students. For example, when explaining the structure of a database, teachers might use an analogy, e.g., a CD collection, an address book or a set of drawers for clothing. At this stage, Shulman suggests that multiple forms of representation are desirable.

One contribution to this process will be the pedagogical content knowledge of selected models used by experts that may help to explain ideas to students, e.g., in packet switching networks, a packet may be envisaged as a fruit bonbon: a chunk of data with a wrapping bearing the address. This analogy helps to describe the nature of packets, and can also illustrate how the data is chopped into pieces before being transmitted because when the bonbons are made a long "sausage" is created which is then chopped into pieces prior to wrapping.

Levin, Stuve and Jacobson (1999) studied peoples' conceptual representations of the Internet and World Wide Web and found a great diversity of mental models. The important difference that they found between experts and novices was that experts were able to be flexible in using a variety of conceptual representations and had the knowledge to enable them to select appropriate representations for particular tasks. Teachers of other subjects have the advantage that their resource base has been building up over a long period, for example secondary science teachers in the UK have had access for years to a monthly publication, the School Science Review, a significant section of which is devoted to ideas from teachers about how to teach particular topics. For example, in a study by Brodie *et al.* (1994) over 100 articles were found in the School Science Review, over a ten-year period, about models to use to teach the concepts in the National Curriculum. Another contribution to the representation process is from the teachers' curriculum knowledge of commercially available materials. In other subjects a range of materials have been published and improved over many years.

A major problem for ICT teachers is the complexity of a key aspect of curriculum knowledge in ICT: the features and functionality of software. There is no doubt that this knowledge is useful for teaching ICT as being able to identify a problem that a student is having with software and intervene can save that student wasting a great deal of time in futile effort. However, it is impossible for ICT teachers to know all the specific features of all the software packages that they use, not least because the software is continually being developed and improved. Teachers don't need to know all the features of all the software as long as they know how to find out about these features. They do need to have an overview of features to be expected in the major types of software such as database systems, modelling environments, Web-page editors, etc. so that they know what they expect to find in a new software package. At the representation stage they need to be able to identify any suitable software for exploring and developing the ideas and skills that are to be taught.

For ICT teachers, another important part of the representation process is identifying suitable contexts to develop ICT knowledge, skills and processes. These contexts may be taken from the school community, e.g., the canteen or the library; the wider community, e.g., a sports centre or local business; or from another curriculum area.

Instructional selection

During instructional selection teachers use their knowledge of learners, ideas, values and beliefs about knowledge as well as pedagogical knowledge and pedagogical content knowledge to select approaches and strategies for learning that suit the content. In well-established subjects, teachers may have developed their knowledge of learners not only from experience, but also from reading about research into how children learn and from curriculum materials. Links between theories of learning and practice of teaching, although not necessarily straightforward or unproblematic, have developed over many years and research into how children learn in science, for example, has led to curriculum development and the production of teaching materials and textbooks in science (e.g., Adey, 2000). Although a large number of textbooks and other curriculum materials have been published recently for ICT, in response to demand, they lack the extensive research base of materials published for science.

A great deal of research and thinking has focused on theories of learning in relation to ICT but this has concentrated on *using* ICT rather than *learning* ICT. For example, Papert's turtle microworld of LOGO (Papert, 1980) was designed to enable pupils to explore and develop their understanding of mathematics. Nevertheless these findings are important because learning ICT depends on using ICT at least as much as for any other subject. Papert (1980) applied Piaget's model of children as builders of their own intellectual structures that has informed much of the developments of constructivist theories of learning (von Glaserfield, 1989; Driver and Easley, 1978). In a later discussion of the role of ICT in learning, Papert (1980) discusses constructionism: a subset of constructivism which is built on the assumption that children will do best by finding for themselves the specific knowledge they need in a supportive environment making use of concrete representation, e.g., a Lego house or computer program. Constructivist theories of learning have had a significant influence on approaches to learning with ICT, e.g., the PALM Project (Somekh and Davies, 1991) was based on constructivist assumptions about learning with ICT. However, in a more recent paper, Somekh (1998) discusses the value of ICT to support learning in relation to other theoretical perspectives including, behavourism, authentic learning and metacognition. Socio-cultural theory can also inform learning in ICT classrooms (McLoughlin and Oliver, 1999).

As Desforges, reported by Somekh (1998), urges, we should not assume that constructivist approaches are always the best for all types of learning. All of the theoretical approaches mentioned here could be applied to justify the choice of an approach to learning a particular aspect of ICT. The ICT curriculum includes some aspects of mathematical and scientific understanding, e.g., data transmission, which may best be tackled using an approach based on constructivist theories of learning. Some factual knowledge such as the Data Protection Act may be learnt using approaches grounded in behavourism. The development of analysis and problem solving abilities may benefit from approaches grounded in authentic learning, contructionism, metacognition and socio-cultural theory. Further investigation of these issues in relation to the content of the ICT curriculum is needed so that the links between theory and practice can be developed.

A first step is to consider how particular knowledge, skills and processes in ICT can be learnt most effectively, bearing in mind not only how computers and communications technology can facilitate learning and general theories of how children learn but also that different students have different styles of learning and different dispositions towards learning. Then we need to decide what teaching methods will facilitate this learning. Methodologies that have been applied in other subject areas may provide pointers, e.g., the Children's Learning in Science Project (CLIS, 1987) describes teaching strategies based on constructivist learning, and the Cognitive Acceleration in Science Education Project has techniques based on cognitive change theories and metacognition (Adey, 1999). Unfortunately, these approaches cannot necessarily be applied directly to ICT since pedagogical concepts are interpreted in a subject-specific manner (Bromme, 1995). Further research is needed in relation to teaching ICT. What interpretation do experienced ICT teachers place on pedagogical concepts such as motivation? What pedagogical content knowledge do they use to select approaches and strategies for learning? Are these effective? Linn and Hsi (2000) report on a collaborative project that has investigated these issues for science education within ICT classrooms and produced a list of "pragmatic pedagogical principles":

- Encourage students to build on their scientific ideas as they develop more and more powerful and useful pragmatic scientific principles.
- Encourage students to investigate personally relevant problems and revisit their science ideas are regularly.
- Scaffold science activities so students participate in the inquiry process.
- Model the scientific process of considering alternative explanations and diagnosing mistakes.
- Scaffold students to explain their ideas.
- Provide multiple, visual representations from varied media.
- Encourage students to listen and learn from each other.
- Design social activities to promote productive and respectful interactions.
- Scaffold groups to design criteria and standards.
- Employ multiple social activity structures.
- Engage students in reflecting on their scientific ideas and on their own progress in understanding science.
- Engage students as critics of diverse scientific information.
- Engage students in varied sustained science project experiences.
- Establish a generalizable inquiry process suitable for diverse science projects.

These are specific to science education but illustrate the types of principles that need to be elucidated for ICT education.

Research into ICT and pedagogy has focused on the use of ICT as a tool rather than the learning of ICT and the need to design a new "integrated pedagogy" has been identified (Cornu, 1995). For example, McLoughlin and Oliver (1999) define pedagogic roles for teachers in a technology supported classroom including setting joint tasks, rotating roles, promoting student self-management, supporting metacognition, fostering multiple perspectives and scaffolding learning. An assumption here is that the use of ICT is changing the pedagogical roles of teachers and a compelling rationale for using ICT in schools is its potential for a catalytic effect in transforming the teaching and learning process (Hawkridge, 1990). A dynamic model for such a transforming pedagogy for Information Technology was derived from the PALM Project (Somekh and Davies, 1991). Some aspects of learning ICT already illustrate aspects of this transformed pedagogy, e.g., from a sequential to an organic structuring of learning experiences which Somekh (1998) explains as structuring a task like a "walled garden" rather than "stepping stones". The area of the garden is defined, but within the wall the learner can explore without restriction. The analysis and design tasks of ICT are generally structured in this way but this still raises many questions for ICT teachers such as: Where are the walls? What support and/or scaffolding need to be provided? Examples of good practice in this process can be found in schools but equally there are instances of students floundering around on their coursework.

Adaptation

Adaptation involves fitting the material to the characteristics of the students, i.e., taking into account their abilities, gender, language, culture, motivation, prior knowledge and skills.

In Figure 3 I have included pedagogical content knowledge of "pivotal cases" an approach used in science education (Linn and Hsi, 2000). These pivotal cases are considered important in science education because children, as a result of their experiences in everyday life develop their own naive theories or misconceptions (Driver and Easley, 1978; Gilbert and Watts, 1983; Driver *et al.*, 1985) which are largely uninfluenced, or influenced in unanticipated ways, by much of science teaching (Osborne *et al.*, 1986).

Students may develop misconceptions in many subject areas but this issue is particularly important in science education because observation of the natural world tends to lead to misconceptions. For example, people know that gardeners apply fertiliser to the soil to make plants grow better so they conclude, not unreasonably, that plants obtain their food from the soil. There is no extensive research base of misconceptions in ICT education, but the widespread use of ICT in society together with the hidden nature of the mechanisms of many ICT devices provides the potential for misconceptions. Examples of the behaviour of computers leading to misconceptions were found during an investigation of primary pupils building and exploring computer-based models (Webb, 1996). Some pupils failed to realise that the computer's behaviour was dependent on the knowledge with which it was programmed. They expected the computer to be "clever" in a similar way to humans. There is also evidence that computer software itself can inhibit conceptual development. Sheeran and Rimmer (1995) report a study of Web browsers that suggested that intermediate users had limited and inappropriate models of Web browsing and that the software was hindering their development of appropriate models. More research is needed to determine the extent and nature of misconceptions in ICT, for example, are misconceptions persistent as in science education or can they be overcome easily by appropriate teaching? Would the use of "pivotal cases" be useful in ICT and what would their characteristics be? Linn and Hsi found that each student drew on different pivotal cases to sort out their thinking. For each class the teacher needed to research students' understanding, analyse their thinking and identify pivotal cases that would build on students' ideas and inspire them to reflect and restructure their views. The teachers then had to use these pivotal cases at appropriate times in discussion with the students. A student that believes that metals have the capacity to impart cold would be asked: How do metals feel in a hot or cold car?

Tailoring

Shulman includes a final step of "tailoring" in the transformation process. This involves fitting the plan to a specific group of students. An example of this might be where an ICT scheme of work is developed for a year group and is then tailored for a particular set or for a group within a class in order to differentiate the material to provide for the needs of all pupils.

Instruction

The process of instruction involves performing a variety of teaching and class management activities. In general terms much of this is observable and well documented in the research literature on effective teaching (e.g., Hay McBer report to the Department for Education and Employment (2000)). However, there is much less research evidence of the teaching of ICT specifically. ICT lessons involve management of a complex range of sources of software and hardware. Although the drive to make greater use of ICT across the curriculum means that all teachers face this challenge, the use of such equipment is essential for ICT teaching and creates regular challenges for the teacher particularly as the tools available are developing rapidly. Another issue, emphasised by Shulman, is that there are powerful relationships between the comprehension of a new teacher and the styles of teaching employed. He illustrates this with an example based on research by Grossman in which a trainee teacher changes from a flexible, interactive style to a didactic teacher-directed style when she has to teach a topic where her comprehension is limited. My experience of trainee teachers of ICT supports this relationship. I have found that a majority of trainee teachers resort to a didactic style for teaching A-level, where their content knowledge is stretched, although they are able to use more interactive approaches for less advanced courses.

Evaluation

Shulman includes in this process all the assessment activities undertaken by teachers and by their students in being assessed and assessing themselves that provide information to be used as feedback to modify teaching and learning activities. Assessment is one of the most important and difficult aspects of the educational process and there is much research evidence to show that the everyday practice of assessment in classrooms is beset with problems and shortcomings (Black and Wiliam, 1998). The issues and suggestions for ways forward are well presented by Black and Wiliam and it is clear that evaluation requires involves a deep grasp of knowledge from all categories as well as drawing on ideas, beliefs and values. In addition, the processes of assessment and instruction are inextricably linked. A detailed consideration of assessment is beyond the scope of this paper but I will outline some issues that have characteristics specific to ICT.

One of the key features of the ICT curriculum, that has been discussed earlier, is the importance of analysis and design tasks. Students need to develop their ability to analyse problems and design solutions so, that at GCSE level, they are able to work independently to produce coursework based on an analysis and design of a system. In order to develop these abilities teachers need to create situations where students feel confident to tackle increasingly complex problem-solving tasks. While students are working on these tasks, teachers need the pedagogical content knowledge to be able to predict problems, identify signs to look for, and which key questions will enable students to make progress. I observed a lesson recently where a trainee teacher had set the students a task to create a house in Logo using one main procedure and a number of sub-procedures. In previous lessons students had written procedures for squares, doors, windows and had worked on another problem where they had broken it down and written procedures that they had then built into a main procedure. However, some had obviously not grasped this process, or could not apply it in the new situation, because the trainee teacher observed several students drawing the whole house in direct mode. She needed to refocus them, so she pointed out to them that they should be using procedures and they replied that it was too difficult. At this point she needed to apply some pedagogical content knowledge: Did they need some more instruction? Could she ask a question? Does she need to model parts of the problem-solving process again? How could she help them to make progress? The students may be having difficulty for a number of reasons including:

- Lack of confidence.
- Fear of failure.
- Misconceptions about the nature of the task: they may not understand the importance for their own learning of using the approach they have been taught. They may believe that the goal of creating a picture of a house is more important than the techniques used.
- Lack of knowledge of a strategy for tackling the problem.

The teacher needs a very specific understanding of those students, their prior achievements, dispositions and self esteem as well as knowledge of a range of questions and strategies that might help them to think about the nature of the problem, the value of procedures and strategies for tackling the problem, etc.

Conclusions

Difficulties in teaching and learning ICT

The model of pedagogical reasoning outlined here is inevitably complex because the teaching and learning situation is complex and, in the best traditions of systems theory (Checkland, 1981), I have taken a holistic view of the process so that important factors and interrelationships are not overlooked.

Table 1. Issues affecting knowledge transformation in the ICT teaching community

Categories of knowledge	Issues affecting availability of knowledge in the ICT teaching community
Content knowledge	Some ICT teachers have inadequate content knowledge. National Curriculum specification lacks clarity. Some ICT teachers are expected to comprehend not only content knowledge for ICT but also how this knowledge relates to the content of other subjects so that both can be taught in an integrated way.
Pedagogical content knowledge	Less well-defined for ICT than for other subjects.
General pedagogical knowledge	Subject specific interpretations are less well-defined for ICT than for other subjects.
Knowledge of learners	Limited research base of students' problems and misconceptions in ICT.
Curriculum knowledge	The collective curriculum knowledge of ICT teachers is less extensive than for other subjects. The importance of using software in ICT makes curriculum knowledge more complex for ICT than for other subject areas. The scope and possibilities are changing rapidly as technology develops.

The analysis of ICT teaching and learning in relation to the model has shown the significance of difficulties in teaching of ICT. The transformation of knowledge, illustrated in Figure 3, is crucial to the pedagogical reasoning process and yet many of the categories of knowledge required for this transformation are lacking in the ICT teaching community. Table 1 summarises the issues affecting the availability of knowledge required for the transformation process in the ICT teaching community.

Where do we go from here?

There are no "quick fixes". In order to carry out the pedagogical reasoning process teachers need knowledge from all the categories described and the importance of knowledge emphasised by Shulman (1987) and Alexander (1992) is confirmed by research into effective teaching (McBer, 2000).

The content of the ICT curriculum needs to be specified more precisely, particularly in the National Curriculum at Key Stage 3. ICT teachers who lack qualifications in ICT at degree level should be encouraged to study the theoretical aspects of the subject rather than focusing predominantly on practical issues. We should move towards a situation where all ICT teachers are educated to degree level in this subject. Whilst these issues relating to content knowledge may require significant resources, they are relatively straightforward to resolve. It is clear from the analysis of the pedagogical reasoning process in relation to teaching ICT that the lack of ICT content knowledge of some ICT teachers is only a small part of the problem. The other categories of knowledge where deficiencies have been identified; pedagogical content knowledge, subject specific aspects of general pedagogical knowledge, knowledge of learners and curriculum knowledge, will require an extensive collaborative effort involving teachers and researchers.

The collective knowledge-base of pedagogical content knowledge and subject specific interpretations of pedagogic knowledge needs to be built by teachers and other researchers sharing ideas through journals and the World Wide Web. Pedagogical content knowledge of the ideas students bring to class can be developed through classroom based action research by teachers. Theories of learning should inform the research. Those that have been discussed in relation to approaches to learning with ICT include constructivist approaches (Somekh and Davies, 1991) behavourism, authentic learning and metacognition (Somekh, 1998) socio-cultural theory (McLoughlin and Oliver, 1999) and constructionism (Papert, 1993). Improvements to the overall transformation process for ICT teachers may best be achieved by groups of teachers and educators working together to discuss which learning theories can best be applied to which areas of content, and then which pedagogical approaches and pedagogical content knowledge will bring about this learning. A set of pragmatic pedagogical principles analogous to that of Linn and Hsi (2000) but specific to ICT may then be established. At the same time research data needs to be collected that links teacher cognition to pupil learning (Desforges, 1995) so that we can discriminate between effective and less effective use of knowledge in terms of pupils' learning.

Curriculum knowledge of relevant software is necessary. However, it is important for teachers not to be overwhelmed by trying to master all the details of software but to focus on the main features of types of software and how to find information about the detailed techniques. The development of well-designed support materials, arising from the elucidation of pedagogic content knowledge and knowledge of learners, is important. Teachers will need to develop their own curriculum knowledge of these resources in order to deploy them effectively. Teachers may then support students to learn to use the software in a constructionist framework where the kind of knowledge students most need is the knowledge that will help them to get more knowledge (Papert, 1993).

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