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REPORT 2:

Literature Review in Thinking Skills, Technology and Learning

A Report for NESTA Futurelab
Rupert Wegerif, School of Education, Open University

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AIMS AND PLAN

The purpose of this report is:

- to clarify what is meant by thinking skills and their relationship to technology
- to identify the role of ICT in promoting thinking skills
- to produce guidelines for the development of digital learning resources to support the teaching and learning of thinking skills
- to evaluate the general direction of research in this area and how this should inform educational practice.

The use of new technologies is often linked to the development of thinking skills or 'higher order thinking'. This review will explore some of the claims that have been made in this area and summarise the useful findings that emerge from research. There is a range of different approaches to understanding thinking skills and learning, each one of which has an impact on how the relationship between thinking skills and technology is conceptualised. The first part of the review explores the literature about teaching thinking skills and their relationship to technology. The second part focuses more on technology, exploring claims that have been made about the relationship of information and communications technologies to the development of thinking skills.

This report has been designed to enable both rapid identification of the key findings and in-depth exploration of the literature.

The key findings and implications of the report are presented within the Executive Summary and Implications Sections. The main body of the review enables readers to explore in more detail the background to these headline issues.

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EXECUTIVE SUMMARY

'Thinking skills' and related terms are used to indicate a desire to teach processes of thinking and learning that can be applied in a wide range of real-life contexts. The list of thinking skills in the English National Curriculum is similar to many such lists in including information-processing, reasoning, enquiry, creative thinking and evaluation. While some approaches to teaching thinking treat such skills as separate, other approaches treat them all as aspects of high quality thinking or 'higher order thinking'. Higher order thinking is said to be complex thinking that requires effort and produces valued outcomes. These outcomes are not predictable because the process of higher order thinking is not mechanical. This makes higher order thinking hard to define. Nonetheless it is possible to recognise higher order thinking and to teach it.

The existence and nature of thinking skills is contested. Few experts in the field would now support the claim that there are universal thinking skills or completely general strategies for learning and problem solving. However it is generally accepted that there is a range of relatively general learning strategies that can be drawn out of some contexts and applied again in new contexts.

Some have criticised the thinking skills movement as being too western, masculine and middle class. However the ideal of being able to listen seriously and empathetically to challenges and to respond to reasonable challenges with reform is central to higher order thinking. Criticisms of particular ideas and practices in the teaching thinking movement that offer reasons can therefore be seen as a part of the self-reforming process of higher order thinking.

Most approaches to teaching thinking do not focus narrowly on procedural skills. In fact, successful thinking skills programmes promote a variety of apparently quite different kinds of things including, strategies, habits, attitudes, emotions, motivations, aspects of character or self-identity and also engagement in dialogue and in a community of enquiry. These 'thinking skills' are not united by any single psychological theory. They are all those things that practitioners believe can and should be taught or encouraged in order to improve the perceived quality and/or the effectiveness of their students' thinking.

HOW ARE THINKING SKILLS, LEARNING AND TECHNOLOGY RELATED?

Technology is a broad term for human tool systems. Human learning and thinking is mediated by tool-systems. These could include words within a language, a notepad and pencil or a computer network. In this review I limit myself to looking at computer-based technologies used to handle information and aid communication (ICT).

Thinking is both individual and social. There is a constant movement of the internalisation of social thinking into individual thinking and externalisation out again into social thinking. Higher order thinking is to be found in the whole movement of thought and not just in the individual part of this movement. Technology, in various forms from language to the internet, carries the external social part of the movement of thought.

Much of the current interest in teaching thinking skills is prompted by technology-driven changes in the nature of work. There is a consensus that new technology is bringing about a new kind of economy in which the main products are information and knowledge rather than material goods. Workers in this new economic climate require transferable thinking skills more than content knowledge or task-specific skills. They particularly require an ability to learn how to learn new things since accelerating technological change is making old skills (and knowledge) redundant and generating needs for new skills (and knowledge).

CAN THINKING SKILLS BE TAUGHT?

There have been several rigorous surveys of the impact of different teaching methods and programmes in the last decade. These provide convincing evidence for the value of teaching thinking skills.

The emerging consensus, supported by some research evidence, is that the best way to teach thinking skills is not as a separate subject but through 'infusing' thinking skills into the teaching of content areas.

WHAT IS THE ROLE OF TECHNOLOGY IN TEACHING THINKING SKILLS?

There are three main ways of thinking about the role of information and communications technology (ICT) in teaching thinking skills: as tutor or teaching machine, as providing 'mind-tools' and as a support for learning conversations.

A review of the evidence suggests that using technology does not, by itself, lead to transferable thinking skills. The success of the activity crucially depends on how the technology is used. Much depends on the role of the teacher. Learners need to know what the thinking skills are that they are learning and these need to be explicitly modelled, drawn out and re-applied in different contexts.

The evidence also suggests that collaborative learning improves the effectiveness of most activities. Tutorial software alone is not effective for developing thinking skills, but tutorial software used as a basis for discussion between learners can be a good way of infusing thinking skills into the curriculum. The effectiveness of computer tools, such as concept maps or programming languages, for teaching transferable thinking skills appears to be enhanced when these are used by learners in pairs or groups. The positive effect of collaborative learning is amplified if learners are taught to reason about alternatives and to articulate their thoughts and strategies as they work together.

Technology is therefore best thought of as a support and resource for dialogues in which thinking skills are taught, applied and learnt. The computer as a tutor and the computer as a tool can both be ways to support and resource such learning conversations. ICT can also itself be a channel carrying learning conversations.

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HOW CAN WE DESIGN TECHNOLOGY TO SUPPORT TEACHING THINKING SKILLS?

The finding that collaboration enhances the learning of thinking skills is important because most software is still designed for individual work. There are several simple design guidelines that could be applied to develop software to support more collaboration (see Section 3.5.3 for details).

Some of the findings about effective teaching for thinking skills could also be incorporated into software design. For example, being explicit about thinking skills, modelling them, designing activities that use the same skills in different contexts and prompting learners to reflect on thinking strategies and articulate them clearly.

Three ways in which the use of ICT can particularly enhance the teaching and learning of thinking skills emerged from the review:

Firstly, through supporting dynamic and multiple representations of information: Visualising patterns in data-sets, for example, allows learners to think at a higher level about statistical relationships.

Secondly, through a certain ambivalence: educational software can act like a teacher to prompt and direct enquiry but can, at the same time, act as a resource while learners discuss and explore ideas. This makes properly designed educational software an effective way of supporting thinking within the curriculum. An example of this productive ambivalence could be to prompt reflection (directive teaching) before, during and after the use of a simulation (discovery learning).

Thirdly, networks can allow students to engage directly in knowledge creation with others who are not physically present. Given the apparent importance of collaborative learning this has significance for home education. Depending on how the activity is arranged, thinking together with others at a distance can be more motivating and can stimulate a higher quality of thought, than thinking together with others in the same classroom.

The best software for teaching thinking skills stems from collaborations between developers and educators or educational researchers.

1 TERMS AND CONTEXT

The main terms of this review all have multiple and disputed meanings. I do not intend to use definitions of these terms as a limit to the scope of the review but as a starting-off point to further exploration.

1.1 THINKING SKILLS

Thinking Skills now feature in the National Curriculum for England where they are described as follows:

By using thinking skills pupils can focus on 'knowing how' as well as 'knowing what' – learning how to learn. The following thinking skills complement the key skills and are embedded in the National Curriculum:

Information-processing skills

These enable pupils to locate and collect relevant information, to sort, classify, sequence, compare and contrast, and to analyse part/whole relationships.

Reasoning skills

These enable pupils to give reasons for opinions and actions, to draw inferences and make deductions, to use precise language to explain what they think, and to make judgements and decisions informed by reasons or evidence.

Enquiry skills

These enable pupils to ask relevant questions, to pose and define problems, to plan what to do and how to research, to predict outcomes and anticipate consequences, and to test conclusions and improve ideas.

Creative thinking skills

These enable pupils to generate and extend ideas, to suggest hypotheses, to apply imagination, and to look for alternative innovative outcomes.

Evaluation skills

These enable pupils to evaluate information, to judge the value of what they read, hear and do, to develop criteria for judging the value of their own and others' work or ideas, and to have confidence in their judgements. (DfES 2002a http://www.nc.uk.net/learn_think.html)

This definition has the advantage of being clear. However it misses out some aspects of thinking skills that most practitioners and experts in the area agree are important.

The most authoritative definition of critical thinking is that of 'The Delphi Report' (Facione, 1990) which is a consensus report from 46 leading experts in the field. This emphasises the holistic nature of critical thinking, the importance of cultivating dispositions and the social context of critical thinking. The executive summary runs to 20 pages and offers 14 useful recommendations. The shortest form of their definition is given below.

We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. CT is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one's personal and civic life. While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. It combines developing CT skills with nurturing those dispositions which consistently yield useful insights and which are the basis of a rational and democratic society. (Facione, 1990)

Philosopher Richard Paul is often described as the leading proponent of teaching critical thinking (e.g. Weinstein, 1993). He would accept the definition above but he also goes further in wanting to add a focus on fostering dialogue. Paul argues

for 'strong' critical thinking, it is important to question one's own assumptions through thinking from the perspectives of others

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that, for 'strong' critical thinking, it is important to question one's own assumptions through thinking from the perspectives of others.

'Meta-cognition' is another term often used as a synonym for thinking skills or higher order thinking. This has been defined as 'awareness of one's own knowledge and the ability to understand, control and manipulate individual cognitive processes' (Osman and Hannafin, 1992 p83). Meta-cognition originates in an information processing model of the mind as something like a computer running both low-level software, to do the basic cognitive processes, and high level software, to monitor and correct the low level software. However this term is increasingly used in contexts where a computer model of the mind is not being assumed. It is often used to refer to any conscious reflection on thinking and learning processes. Some 'skills', habits and dispositions important to good thinking in many contexts are not meta-cognition in this sense. Therefore I believe that the term 'meta-cognition' does not refer to all thinking skills but to that sub-set of such skills that depend upon becoming more aware of thinking processes.

Sharon Bailin (1998) opposes the use of the term 'skills' on the grounds that its use in psychology leads to it being taken to imply a property of the brain. She argues that critical thinking is essentially a normative and not a descriptive term. She means by this that critical thinking is not merely a description of how we think but is concerned with how we think well. More precisely, it is about the quality of reasoned judgements, and this can be assessed by shared criteria. Building a bridge that collapses will involve most of the same cognitive and meta-cognitive strategies, and activate the same regions of the brain in the engineers, as building a bridge that stands. But we want to promote the skills that went into building the bridge that stands. Thinking skills are therefore not just about abstract cognitive processes – they are about the quality of socially embedded decision making processes.

However Carol McGuinness argues in favour of retaining the term 'thinking skills':

> ...the idea of thinking-as-a-skill continues to have both theoretical and instructional force. Firstly it places thinking firmly on the side of "knowing how" rather than "knowing that" in the long standing philosophical debate about the nature of knowing. And secondly much of what we know about skill learning can be usefully applied to developing thinking...
> (1998, p4/5)

McGuinness goes on to mention how well the 'skills' terminology fits with the increasing importance of ideas of apprenticeship to teaching and learning. I agree with Bailin that understanding and promoting good thinking requires working with shared criteria for the evaluation of arguments. However I also agree with Carol McGuinness that the idea of thinking-as-a-skill is a useful one for practitioners. In everyday language to describe someone as skilled at something - say at ballet dancing or wood-carving - implies a public performance to which shared criteria can be applied. There is no need to assume a more specialist meaning for the term 'skills'.
Use of the term 'thinking skills' might also be challenged by those who see quality thinking as a more holistic or unitary phenomenon which combines many specific skills but is more than any of them. Lauren Resnick (1987), chaired a working party for the National Research Council in the USA on teaching thinking. She concluded that 'higher order thinking' is complex and effortful thinking that produces valued outcomes. These valued outcomes are not easy to predict in advance because higher order thinking, unlike computation for example, is not mechanical. Higher order thinking, she concluded, is very hard to define but easy to recognise. This is an important and interesting claim. Clearly the art of thinking well is difficult to understand. Nonetheless if we know how to recognise it when it happens this implies that we do in fact understand it tacitly or intuitively. Guy Claxton argues (1999) that the value of intuitive 'soft thinking' of this kind should not be rejected in favour of more clearly articulated theoretical 'hard thinking'. It seems likely that, when it comes to questions such as the nature of thinking, our intuitive understanding far outstrips knowledge that we could make explicit in a theory. This is probably less of a problem for practitioners, who often work effectively guided by intuitive knowledge alone, than for many academics.

In Bloom's taxonomy of the types of thinking found in education, higher order thinking is said to build upon lower order thinking, or basic skills. Reading is seen as a basic or lower order skill, for example, while evaluating what one reads is seen as a higher order skill. This division of thinking into higher order and lower order has been questioned by those who argue that thinking is holistic rather than hierarchical. However the term 'higher order thinking' is often used, as by Resnick referred to above, in a non-technical way to indicate the kind of thinking that is to be particularly valued and that educators wish to promote (Resnick, 1987). I will use the term higher order thinking in this sense.

Most approaches to teaching thinking do not focus narrowly on procedural skills. In fact successful thinking skills programmes promote a variety of apparently quite different kinds of things including, strategies, habits, attitudes, emotions, motivations, aspects of character or self-identity and also engagement in dialogue and in a community of enquiry. These thinking skills are not united by any single psychological theory. Most practitioners do not mind combining the promotion of automatic habits through positive feedback (learning as behaviour modification) and teaching conscious meta-cognitive strategies such as always seeking an alternative view (from cognitive learning theory) with creating a community of enquiry in the classroom (learning as social participation). The main concern of most practitioners is that everything they do contributes to the goal of teaching better thinking. Thinking skills are therefore essentially those things that practitioners believe can and should be taught or encouraged in order to improve the perceived quality and/or the effectiveness of students' thinking.

'higher order thinking' is complex and effortful thinking that produces valued outcomes

1.2 TECHNOLOGY

Technology originates in a Greek term meaning the systematic treatment of an art or craft. It has come to be used to refer to physical and symbolic tool systems. Although less controversial than either

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thinking skills or learning, the scope of the term technology is nonetheless disputed. Reeves (1998) and Salomon (1992) seek to make a clear distinction between technology and media:

> Computer-based technologies cannot be regarded as "media," because the variety of programs, tools, and devices that can be used with them is neither limited to a particular symbol system, nor to a particular class of activities... In this light, "the computer" is in fact a "multifaceted invention" of many uses, a symbolic tool for making, exploring, and thinking in various domains. It is used to represent and manipulate symbol systems – language, mathematics, music – and to create symbolic products – poems, mathematical proofs, compositions. (Salomon, 1992, p892)

Salomon's distinction between media as symbol systems and technologies as tools or vehicles for sharing media is an interesting one. It makes sense if we think about his example of language and music as media and computers as a technology serving as a conduit for these media. There is no need to invoke a shared medium when I use my PC to listen to a CD-ROM while at the same time using the keyboard to type a letter. Although both activities are supported by a computer they could equally as well have been supported by different machines. However Salomon's distinction breaks down if we consider hyper-media texts that are only made possible by the use of computers. I could, for example, compose a web-site that combined clips of the music that I was listening to with cuttings from the letter that I was writing. It seems reasonable to suggest that skill at creating hyper-media texts involves a new kind of literacy that is dependent on computer-based technologies (Rassool, 1999). I will therefore not distinguish closely between new media and new technology in this review.

We do not think entirely on our own, we think with the help of tools and tool-systems. These could include words within a language, a notepad and pencil, or a computer network. In education the term technology could refer to books, pencils, television, even chalk and blackboards. I will limit it, for the purposes of this review, to information and communication technologies (ICT). This means quite simply, computer-based technologies used to handle information and aid communication. The phrase 'Information and Communications Technology' was coined by Stevenson in his 1997 report to the UK government and promoted by the new National Curriculum documents for the UK in 2000. (FOLDOC, 2002)

1.3 LEARNING

The term learning can mean a variety of different things. There are obviously differences between learning that the Battle of Hastings took place in 1066, learning how to play tennis and learning how to love - just three examples of current usage. As well as there being different kinds of learning there are also different theoretical approaches to the study of learning. Four of the most influential of these approaches are summarised quite neatly in a table on the, generally excellent, informal education web-site (http://www.infed.org/). I have adapted this table slightly by changing names and adding a row to deal with views of transfer.

Four orientations to learning (after Merriam and Caffarella, 1991, p 138)

ASPECT	BEHAVIOURIST	COGNITIVIST/ CONSTRUCTIVIST	HUMANIST	PARTICIPATORY
LEARNING THEORISTS	THORNDIKE, PAVLOV, WATSON, TOLMAN, SKINNER, SUPPES	PIAGET, AUSUBEL, BRUNER, PAPERT	MASLOW, ROGERS	LAVE, WENGER, COLE, WERTSCH, ENGESTROM
VIEW OF THE LEARNING PROCESS	CHANGE IN BEHAVIOUR	INTERNAL MENTAL PROCESS INCLUDING INSIGHT, INFORMATION PROCESSING, MEMORY, PERCEPTION	A PERSONAL ACT TO FULFIL POTENTIAL	INTERACTION /OBSERVATION IN SOCIAL CONTEXTS. MOVEMENT FROM THE PERIPHERY TO THE CENTRE OF A COMMUNITY OF PRACTICE
LOCUS OF LEARNING	STIMULI IN EXTERNAL ENVIRONMENT	INTERNAL COGNITIVE STRUCTURING	AFFECTIVE AND COGNITIVE NEEDS	LEARNING IS IN RELATIONSHIP BETWEEN PEOPLE AND ENVIRONMENT
VIEW OF TRANSFER	COMMON ELEMENTS SHARED BY DIFFERENT CONTEXTS	OVER-ARCHING GENERAL PRINCIPLES	CHANGES IN SELF-IDENTITY AS A LEARNER	TRANSFER PROBLEMATIC
PURPOSE IN EDUCATION	PRODUCE BEHAVIOURAL CHANGE IN DESIRED DIRECTION	DEVELOP CAPACITY AND SKILLS TO LEARN BETTER	BECOME SELF-ACTUALIZED, AUTONOMOUS	FULL PARTICIPATION IN COMMUNITIES OF PRACTICE AND UTILIZATION OF RESOURCES
EDUCATOR'S ROLE	ARRANGES ENVIRONMENT TO ELICIT DESIRED RESPONSE	STRUCTURES CONTENT OF LEARNING ACTIVITY	FACILITATES DEVELOPMENT OF THE WHOLE PERSON	WORKS TO ESTABLISH COMMUNITIES OF PRACTICE IN WHICH CONVERSATION AND PARTICIPATION CAN OCCUR

In the 1996 Handbook of Educational Psychology, James Greeno, Allan Collins and Lauren Resnick, three very authoritative names in the field of educational research, define learning and transfer as follows:

> Learning is the process by which knowledge is increased or modified. Transfer is the process of applying knowledge in new situations. Educators want the knowledge that is acquired in school to apply generally in students' lives, rather than being limited to the situations in classrooms where it is acquired. That is to say, they want the knowledge to transfer.

I accept this definition of learning. It has the advantage of being very broad. Greeno, Collins and Resnick argue that there are three main schools of learning theory in educational psychology:

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- behaviourist/empiricist: learning as acquiring and applying associations
- cognitivist/rationalist: learning as acquiring and using conceptual and cognitive structures, and
- situative/pragmatist-sociohistoric: learning as becoming attuned to constraints and affordances through participation.

These three schools are a version of three of the four traditions in the table above. In their detailed account of these three different approaches to understanding learning and transfer Greeno, Collins and Resnick demonstrate that each tradition has made a valuable contribution to understanding some aspects of learning. Behaviourist approaches have worked well for some basic skills learning, the cognitivist tradition has done some good work on meta-cognition and conditions of transfer while the social situationists have shown the importance of cultural tool-systems and communities of learning. However each approach also has weaknesses and this is an area of study that is open and constantly evolving.

I will return to this account of the main divisions in educational psychology in part three of this report in order to consider the impact of each of these three approaches on ways of thinking about the role of new technology in learning.

1.4 THINKING SKILLS, TECHNOLOGY AND LEARNING IN CONTEXT

thinking skills are often said to be the kind of skills that people need to make decisions

Thinking skills are often said to be the kind of skills that people need to make decisions (e.g. Ennis, 1996). There used to be many fewer decisions for most people to make. Plato, for example, advocated teaching reason only to the small elite who would have to take all the major decisions, (and even then only when they were over thirty!) See Plato's Republic, (1970). The majority of the population of his ideal 'Republic' would be given a more vocational education fitted to their station. Plato saw little point in equipping them with skills that they would not have an opportunity to use. Plato's point makes some sense in the economic circumstances of Ancient Greece and a similar principle was applied until quite recently in the UK.

One point of agreement running through almost every article that I have read on teaching thinking skills is that the need to teach thinking skills now is rooted in our particular socio-historical situation. Thinking skills are everywhere described as 'skills for the new century', 'skills for the workers of the future' or 'skills for the knowledge society'. Basically the argument is that changes in the economy require more people to be more actively involved in decision making than was ever the case before. It is usually also claimed that these changes in the economy are driven by the development of new information and communication technologies. The thinking skills literature is full of references to the need to produce new knowledge workers for the new knowledge economies (e.g Swartz, 2001). One idea behind this is that new technologies have led to increasing automation of the kinds of work that computers can do thereby forcing people into jobs where they have to take more subtle decisions and solve more complex problems (Levin and Rumberger 1995 quoted in Rassool, 1999 p153). A second key idea is that new technology in the work place has led to rapid and accelerating changes in practices and that this puts a premium on learning how to learn, since anything more specific that children are taught in school is seen as likely to be out of date by the time they leave.

The aim of this review is to explore the relationship between technology and thinking skills. One dimension of this relationship is that the kinds of thinking that people value most depend on the cultural and historical context and particularly upon the kind of technology that people have at their disposal to help them think. The Ancient Greeks had very simple technologies and they valued that kind of thinking that distinguished them most from the animals around them. Aristotle defined man as a rational animal meaning that only man could measure, judge and decide on the basis of reasons (Aristotle, 1987). Before the arrival of computers in human history it seemed natural to many to describe 'higher order thinking', or rationality, in terms of abstract reason on the model of formal logic or mathematics. This kind of thinking was really hard, potentially very useful and only a few people could do it well. Computers, however, find formal reasoning very easy. What they find hard is the sort of things most people take for granted like coming up creatively with new ways forward in complex, fast-changing and open-ended contexts where there is no certainty of being right. Holding an ordinary conversation is typical of what it is that humans find natural but computers find extremely hard.

It is not surprising therefore that, as the use of computer-based technology has become more ubiquitous, the focus of thinking skills research has shifted away from the sort of things that computers can do for us, such as formal reasoning or algorithmic problem solving, towards the sort of things that computers cannot yet do. Instead of contrasting human thinking to the thinking of animals, human thinking is beginning to be contrasted to the thinking of machines (e.g Penrose, 1994: Hobson, 2002). The focus of published thinking skills research is shifting away from teaching logic and towards a greater interest in supporting complex unpredictable thinking (Resnick, 1987), engagement in dialogues (Paul, 1987), intuition (Claxton, 1999) and creativity (Bailin, 1994). One way in which thinking skills are related to developments in technology is therefore simply that the human skills that we value most, and that are rewarded the most, are those skills that computers cannot yet imitate.

1.5 SUMMARY OF SECTION 1

Thinking skills are hard to define but possible to recognise and to teach. The list of thinking skills in the UK National Curriculum is a reasonable one and similar to many: information-processing, reasoning, enquiry, creative thinking and evaluation. Such skills are not discrete entities but part of larger contexts. Most approaches to teaching thinking skills include broader issues such as engagement in dialogue, the formation of self-identity and the importance of a supportive culture.

Technology is a broad term for human tool systems. I will limit it, for the purposes of this review, to computer-based technologies used to handle information and aid communication (ICT). The concept of learning is bound up with the concepts of knowledge and of transfer.

CAN WE OR SHOULD WE TEACH THINKING SKILLS?

Learning is generally defined as the increase or modification of knowledge. Teachers want the knowledge that is learnt in school to be applied outside school. They are therefore interested in the transfer of knowledge from the context in which it is acquired to other contexts. The nature of knowledge and of transfer are conceptualised differently by different traditions in educational theory. For the topic of this review the three most important schools of thought are probably the behaviourist, the cognitivist and the participatory.

Much of the current interest in teaching thinking skills is prompted by technology-driven changes in the nature of work. There is a consensus that new technology is bringing about a new kind of economy in which the main products are information and knowledge rather than material goods. Workers in this new economic climate require transferable thinking skills rather than content knowledge or task-specific skills. They particularly require an ability to learn how to learn new things since accelerating technological change is making old skills (and knowledge) redundant and generating needs for new skills (and knowledge).

2 CAN WE OR SHOULD WE TEACH THINKING SKILLS?

The existence, value and nature of thinking skills continue to give rise to a great deal of debate in academic journals and books. Some of the key questions that emerge from this literature are:

- do general thinking skills exist?
- if so are they individual or social?
- are critical thinking skills white, male and middle-class?
- should thinking skills be taught separately or should they be taught within subjects?
- are studies of the brain relevant or not?
- is there any good evidence for the value of teaching thinking skills?

I will deal briefly with each of these questions in turn indicating how answers to these questions relate to the use of new technology as means for promoting thinking skills.

2.2 DO GENERAL THINKING SKILLS EXIST?

Some philosophers and some psychologists challenge the existence of general thinking skills.

2.2.1 THE ARGUMENT AGAINST THINKING SKILLS IN PHILOSOPHY

John McPeck argued that thinking is always thinking about something and therefore it does not make sense to talk about thinking in general (McPeck, 1981). For McPeck the different academic subject areas are different forms of life with their own unique logics. Teaching general critical thinking skills is therefore a serious mistake which will lead to superficial learning. Similar arguments are made by the influential US educationalist E. D. Hirsch (1987). In Britain something like this position appears to have strong support amongst philosophers of education (Johnston, 2000)

2.2.2 THE ARGUMENT AGAINST THINKING SKILLS IN PSYCHOLOGY

In educational psychology the argument against thinking skills is much the same as that in philosophy but presented differently. Proponents of the view that learning is 'situated in contexts' and/or is always about 'participation in communities of practice' oppose their 'Specific Learning Model' (Rogoff, Gauvain and Ellis, 1991, p315) to the more traditional 'Central Processor Model' of the brain. This Specific Learning Model follows from claiming that 'thinking skills' are embedded in 'cultural tool systems', especially local ways of using language to get things done ('language' here is considered a tool-system). On this model what is learnt in the context of one cultural task can only be assumed to relate to that task. The implication is that teaching transferable skills is just a myth. This position is often supported by the claim that there is no real evidence for transfer (e.g. Hennessy et al, 1993).

2.2.3 RESPONSES TO THESE ARGUMENTS

The most balanced rebuttals of arguments against the possibility of teaching thinking skills point out that they fail to engage with the reality of contemporary approaches to practice (Weinstein, 1993: Higgins and Baumfield, 1998). The argument that all thinking is thinking about something is a reasonable objection to some attempts to teach a pure and abstract logic of good thinking. There is little evidence for the automatic transfer of general thinking skills that a 'central processor model' of the mind would predict (Perkins and Salomon, 1989). Apparently, against the claims of Piaget (1950), the brain learns things embedded in a rich context and does not automatically extract general logical rules that could be applied to other contexts (Claxton, 1999, p203). However this does not mean that we cannot be taught to extract useful general rules - there is plenty of evidence (quoted below) that we can, in fact, do just that.

Few experts in the field would now support the claim that universal thinking skills exist outside of any context. Thinking skills are not an abstract logical structure. They are embodied practical skills that are learnt in a context and then, often with the help of teachers, taken out from that context to be applied in a new context. If these relatively general skills or strategies are taught in an abstract form, then careful work needs to be done by teachers to embed them in a context where they can be applied.

Much recent research has suggested, for example, that the development of higher order thinking, including the development of self-awareness, depends upon the child's early engagement in dialogues with their primary care-giver (usually their mother, see Forrester, 1992 and Hobson, 2002). A capacity to engage effectively in dialogue with other people, and with tasks, appears to lie behind many of the techniques, habits and dispositions referred to in the literature on thinking skills. If so this capacity appears to be a holistic and embodied skill that is learnt in one context and applied in many other contexts.

One implication of the conclusions that emerge from this debate is that learning how to work a complex video-game is not necessarily going to help you do better at a

few experts in the field would now support the claim that universal thinking skills exist outside of any context

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maths exam even though, logically, some of the problem-solving and reasoning strategies involved are the same in both cases. A brief summary of research on the use of LOGO given in part 3 of this review shows that this conclusion has been confirmed in practice. However, this does not mean that transfer is impossible – it means that some thought and effort needs to be put into achieving it. If, for example, a video-game involves problem solving strategies, then the nature, scope and limits of the strategies need to be made explicit, and examples need to be offered of the same strategy used in new contexts with new content. Simulations that allow learners to practice these strategies in life beyond video games could be used to help bridge the transfer of general skills from one context to another.

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2.3 ARE THINKING SKILLS INDIVIDUAL OR SOCIAL?

Thinking skills are often seen as attributes of individuals, perhaps the property of individual brains. However there has been a major shift in both philosophy and psychology towards seeing thought as essentially social not individual. The increasing status given to the ideas of educational psychologist Lev Vygotsky supports this tendency in psychology. Vygotsky, a Marxist, is often presented as providing a psychological version of Marx's claim that individual thought is a product of the social and historical context (e.g. Edwards, 1996, p43). In particular Vygotsky claims that language is a tool-system that mediates the development of thought. This fits well with research on distributed cognition, which suggests that cognition is not located in individuals so much as in systems that, while they may include people, also include objects and technologies (Salomon, 1993).
The roots of critical thinking are not necessarily individualist. John Dewey, an advocate of teaching thinking, saw thinking as a product of social interaction and teaching thinking as a way of contributing to the creation of a better society (Dewey, 1933). Jurgen Habermas (1991), has argued in a similar way that rationality implies the ideal of a more genuinely democratic society in which all relevant voices are really listened to and decisions are taken on the basis of the quality of arguments rather than on the basis of coercive power. One educational implication of Habermas' argument is that teaching thinking skills involves changing the social context to create conditions that at least approximate to what he calls an 'ideal speech situation'. Experimental evidence, as well as Vygotskian theory, suggests that the quality of individual thinking reflects the quality of collective thinking and vice versa (Wegerif, Mercer and Dawes, 1999: Mercer, 2000).

Growing acceptance of the idea that thinking is embedded in social contexts can be seen reflected in the language used to discuss thinking skills. There is an increasing use of collective terms such as 'thinking classrooms' (McGuinness, 1998), 'thinking schools' (Wilson, 2000) and 'communities of inquiry' (Lipman, 1991). 'Philosophy for Children', a popular approach to teaching thinking skills, already works primarily by drawing children into discussions and turning the classroom into a community that supports thinking (Fisher, 1998).

The new field of the study of consciousness might have something interesting to say about this issue.

Consciousness is clearly important to many approaches to higher order thinking, in particular the idea of using meta-cognitive strategies to become more aware of one's own thinking. In some ways consciousness is inescapably an individual property. But interestingly the word is formed from Latin roots meaning 'knowledge with another'. One implication from the work of Hobson (2002: 1998) quoted earlier, as well as other approaches to understanding consciousness, is that individual self-consciousness is formed out of internalised dialogue. In other words to be aware of something at all is to see it as if from the perspective of other people and so to be potentially able to express it and to share it with other people. From this and other sources (e.g Wittgenstein's private language argument, 1967) it seems that there are good reasons to think that both self-consciousness and higher order thinking are social in origin. In other words thinking skills originate in conversations where we learn to reason, to evaluate, to join in creative play and to provide relevant information. However, at the same time it is clear that all social thinking could be seen as being made up of individual contributions and is rooted in potentially measurable individual brain processes. There is a constant movement of the internalisation of external thinking into individual thinking and externalisation out again by individuals who create and shape social thinking. To understand this vision of thinking as a whole flowing movement it might help to think of the way that creative speakers and writers (i.e. all of us) both use words and phrases that they find already there, external to them, in the language and yet also shape the development of that shared resource of language. One important conclusion from this debate is that higher order thinking is to be found in the whole circular movement of thinking and not just in the most private individual moment of it.

In the past thinking skills interventions have focussed on supporting the internal moment of the circular movement of thinking and the internalisation process. However, if higher order thinking is to be seen in the whole movement, then it follows that it is may also be valuable to improve the quality of social thinking and the quality of the externalisation process. Technology, in various forms from language to the internet, carries the external form of thinking. Technology therefore has a role to play through supporting improved social thinking (eg providing systems to mediate decision making and collective reasoning) and also through providing tools to help individuals externalise their thinking and so to shape their own social worlds.

in other words thinking skills originate in conversations where we learn to reason, to evaluate, to join in creative play and to provide relevant information

2.4 ARE CRITICAL THINKING SKILLS WHITE, MALE, AND MIDDLE-CLASS?

Some argue that critical thinking skills are not really of general value but are a product of the experience of a particular social group usually described as white, male and professional or managerial. Ruqaya Hasan, for example, in a study that shows that there is more language of explicit problem solving and reasoning in the homes of managers and professionals than in blue collar homes, claims that the value given to this way of using language reflects Marx's claim that 'in every age the ideas of the rulers are the ruling ideas' (Marx, 1977 quoted in Hasan 1992). Harvey Siegel (1987) and Sharon Bailin (1998) respond to this kind of challenge

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defining thinking skills in a narrow way often reflects the experience and self-interest of a particular social group

with the argument that criticisms of critical thinking already imply critical thinking and can only be assessed through the giving and evaluating of reasons. However this focus on explicit reasoning fails to fully address some of the concerns expressed. Feminist philosopher, Seyla Benhabid (1992) seems to be have more insight into why certain groups feel excluded by the ideal of critical thinking and offers what I think is a constructive way forward. Her argument, based upon Habermas, is that, if we are to bring up children in peace we actually do need some sort of ideal of reason or at least an ideal of 'being reasonable'. This ideal is about how real people solve their problems without resorting to violence through engaging in dialogues informed by an attitude of care and respect. There is a view that emerges from the literature that this 'concrete ideal' of dialogue across difference is the origin of 'higher order thinking'.

For Richard Paul, as was noted earlier, critical thinking in the strong sense has to be 'dialogical'. What he means by this is that the critical thinker has an obligation to question his or her own assumptions in order to try to understand the perspective of others. If, as Seyla Benhabid suggests, reason is situated in real dialogues then, in the course of such dialogues, assumptions about what constitutes good reasoning will themselves have to be questioned and allowed to evolve. If there are different ways of thinking with something to offer – and claims have been made for the value of more intuitive and holistic feminine and non-western ways of thinking - then this should emerge in such genuine 'strong' critical thinking dialogues. But any such evolution of our understanding of higher order thinking would only serve to strengthen the process of higher order thinking itself, if this is understood as essentially and originally 'dialogue across difference' (Burbules and Rice, 1991).

There is already evidence that access to technology at home enhances educational achievement (Reeves, 1998) and it is acknowledged that access to ICT in homes is patterned along socio-economic lines. If teaching thinking equips children for individual success in a competitive market place and no more than that, then teaching thinking with computers could prove to be another way to reproduce social inequality.

It may well be that defining thinking skills in a narrow way often reflects the experience and self-interest of a particular social group. On the other hand, if, as the evidence suggests, higher order thinking has a social side as well as an individual side, then teaching thinking requires the promotion of more intelligent forms of collective thinking. Some writers, indeed, have brought out the connection between teaching thinking skills with ICT and the promotion of an intelligent and responsive global democracy (e.g Cobb, 2002: Rassool, 1998).

2.5 SHOULD THINKING SKILLS BE TAUGHT SEPARATELY FROM CONTENT AREAS?

Different positions in the debate about the nature of thinking skills suggest different responses to the question of how to teach thinking skills. Belief in what has been called 'the central processor model' of the mind tends to suggest that teaching thinking skills directly in a separate programme will automatically have a general impact. There are many such separate programmes: Feuerstein's instrumental enrichment (Blagg, 1991) Lake and Needham's top ten thinking tactics (Lake and Needham, 1993), de Bono's CORT (1976) and Lipman's own 'Philosophy for Children', are examples (Lipman, 1991).

The argument that thinking skills are specific to subject areas, however, suggests developing thinking skills within each subject area separately. McGuiness makes a good argument for a third approach, which, following Swartz and Parks (1994) she calls the 'infusion' approach. The idea is that teaching curriculum content is 'infused' with the teaching of thinking skills. This approach perhaps follows from the claims above that while there are general thinking skills, teaching them needs to be carefully contextualised to be effective. Some examples of infusion programmes are McGuinness' ACTs (McGuinness et al, 1997) and Sharon Bailin's approach to teaching critical and creative thinking in Canada (Bailin, 1994). In the UK this approach is exemplified by 'Thinking Together' (Mercer, 2000: Dawes, Mercer and Wegerif, 2000), Robert Fisher's UK approach to 'Philosophy for Children' (Fisher, 1998) and 'Thinking Through Primary Teaching' (Higgins, 2001; Leat and Higgins 2002).

The consensus seems to be that hard independent evidence for the success of separate thinking skills programmes is limited. (Resnick, 1987; Craft, 1991; Greeno, Collins and Resnick, 1996). This consensus, in combination with the shift in educational theory towards the situated and the social, mean that there is a direction towards thinking skills programmes being embedded more in content area teaching. This has implications for the design of educational software to support thinking skills. Programmes that teach 'problem solving' with no particular content area are less likely to be useful than programmes that teach problem solving in the context of maths or perhaps in the context of sorting out social security benefits.

2.6 WHAT CAN BRAIN STUDIES TELL US?

Much cognitive theory approaches the brain indirectly, trying to infer through reverse engineering what is really going on (Pinker, 1998). It is only relatively recently that techniques have been developed that can allow more direct access to the working of the brain. New brain imaging techniques (PET and fMRI) measure brain activity by detecting changes in blood flow during particular tasks in human subjects, while EEG and MEG measure electrical and magnetic activity arising from neurons on the surface of the brain (Blakemore and Frith, 1998). This new access seems to have prompted a tendency to appeal to the authority of brain studies for claims about teaching thinking.

Some of the ways in which brain science is used to justify particular teaching techniques appear to be unwarranted leaps from the evidence. The newly popular approach to teaching called 'Accelerated Learning' (Alistair Smith, 1996) claims to be based upon the findings of brain research. The success of accelerated learning with teachers implies that it may have some excellent new pedagogical ideas. These may well have been inspired by brain research, but claims that they are based directly upon

programmes that teach 'problem solving' with no particular content area are less likely to be useful than programmes that teach problem solving in the context of maths or perhaps in the context of sorting out social security benefits

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brain research are exaggerated. Similarly, mind-mapping might have pedagogical value but its promoters are not really able to claim, as they do, that mind maps work because they duplicate the way that the mind works (Buzan and Buzan, 2000: Jonassen, 2000). We still know very little about how the mind really works. A serious expert review of the evidence by Sarah-Jayne Blakemore and Uta Frith of the Institute for Cognitive Neuroscience in London finds that there are currently few practical educational implications that can be safely drawn from research on the brain.

It seems most likely that the main impact of neuroscience on education will be felt in the field of learning disorders. Research to date has implications for what to do when the brain goes wrong. The implications are less clear for what to do when brains function normally or how to improve normal functioning. (Blakemore and Frith, 2000 p44).

However Blakemore and Frith report evidence for claims that are of interest to the project of teaching thinking:

- that the brain can learn complex patterns implicitly without conscious awareness
- that procedural learning (know how) and declarative learning (know that) make use of quite different parts of the brain
- that the brain continues to be flexible throughout life and can change measurably as new skills are learnt.

Thinking remains a deeply mysterious business. Both the dry abstractions of cognitive psychology and the new orthodoxy that everything is 'situated social practice' fail to seriously address our everyday experience of consciousness. Brain scanning techniques, which get closer than ever before to the real brain processes behind thinking and consciousness, are therefore a valuable contribution to the debate. Neuro-chemist Susan Greenfield, for example, argues, from research evidence, that the subjective experience of depth of consciousness is directly related to the size of the temporary neuronal assembly (all the neurons linked up in a co-ordinated way) around a stimulus and inversely related to the strength of emotion (Greenfield, 2000). This is relevant to the question of thinking skills. Both Salomon and Globerson (1987) and Claxton (1999) argue that some forms of transfer from learning with technology depend upon the extent of 'mindfulness', by which they mean much the same as Greenfield's 'depth of consciousness'. Teaching thinking skills is not just about mental mechanisms, verbal strategies, or promoting a positive self-image – it is also about expanding consciousness. The wonder of brain science is that it may well, one day soon, make such woolly sounding claims rigorously assessable.

teaching thinking skills is not just about mental mechanisms, verbal strategies, or promoting a positive self-image – it is also about expanding consciousness

2.7 IS THERE EVIDENCE FOR THE VALUE OF TEACHING THINKING SKILLS?

I have already noted that several reviewers have argued that there is little hard evidence for the effective teaching of transferable thinking skills (Resnick, 1987: Craft, 1991). However in the last decade a number of studies and reviews have found considerable evidence for the value of teaching thinking skills.

CASE (Cognitive Acceleration through Science Education) is one of the most successful and well-evaluated programmes in the UK. Incorporating discussion about science problems in classroom, CASE is directed towards scientific reasoning for 11-14 year-olds. CASE succeeded in raising pupils' grades in GCSE examinations (on average one grade) two to three years after the programme had been completed (Adey and Shayer, 1993, 1994). Recent extension of the CASE programme into Key Stage 1 has also produced evidence of impact on children's learning (Adey, Robertson and Venville, 2002).

A recent meta-analysis of the impact of Feurstein's Instrumental Enrichment found that overall, the programme had a positive impact (Romney and Samuels, 2001). A total of 40 controlled studies, comprising 47 different samples, were examined. Significant, though modest, average effect sizes were found in all three areas - achievement, ability, and behaviour - with the most extensive improvement being made in ability. Gains in spatial/perceptual ability were related to the length of the intervention (number of hours), and the impact on self-esteem was related to age.

Marzano (1998) analysed 4000 intervention studies in education involving over 1,237,000 subjects. Marzano found that nearly all interventions worked to some extent but that interventions that focussed on the level of meta-cognition, (ie teaching thinking and learning strategies), and the level he called the self-system (ie how students feel about themselves as learners) were most effective in improving measures of learning.

Marzano's findings strongly support the success of teaching thinking skills if we translate this to mean the teaching of meta-cognitive strategies. Marzano writes that:

> Specifically, instructional techniques that employed the metacognitive system had strong effects whether they were intended to enhance the knowledge domains, the mental process within the cognitive system, the beliefs and processes within the self-system, or the processes within the metacognitive system itself.

Similarly, teaching that specifically focused on emotions and sense of identity (the self system) had a powerful effect on learning gains at every level. Implicit in this finding is a transfer effect from teaching focussing on attitudes and feelings to gains in learning measures.

Hattie, Biggs and Purdie (1996) conducted a meta-analysis of 51 study skills interventions. They found that 'Despite, perhaps, the conventional wisdom, most intervention does work most of the time' (1996, p128). However separate general study skills programmes were found to be much less effective than teaching meta-cognitive strategies as part of the teaching of content within courses.

The statistical evidence now seems convincing. But another kind of evidence that should not be ignored is the evidence of experience. We all have experience as both teachers and learners. We all know intuitively that it is possible for learning to change people and to become part of them. We also know that it is possible to learn skills that are used outside the context in which they were taught. That is how we can think at all when faced with a

separate general study skills programmes were found to be much less effective than teaching meta-cognitive strategies as part of the teaching of content within courses

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completely new challenge. The fact that these things sometimes prove hard to evaluate in a rigorous way should not lead us to deny such obvious and everyday experience. It is intuition based upon this kind of experience that lies behind the interest of so many teachers in teaching thinking skills. In my view that intuition is not misguided.

2.8 SUMMARY OF SECTION 2

The existence and nature of thinking skills is contested. Few experts in the field would now support the claim that there are universal thinking skills or completely general strategies for learning and problem solving. However there is consensus that there are a range of relatively general learning strategies that can be disembedded from some contexts and re-embedded again in new contexts.

Thinking is indissoluably both individual and social. There is a constant movement of the internalisation of social thinking into individual thinking and externalisation out again by individuals into social thinking. Higher order thinking is to be found in the whole flowing circular movement of thinking and not just in the individual moment of it. Technology in various forms, from language to the internet, carries social thinking. Technology therefore obviously has a role to play in supporting higher order thinking.

Many have criticised specific ideals of higher order thinking and thinking skills as being too western, masculine and middle class. However the ideal of being able to listen seriously and empathetically to challenges and to respond to reasonable challenges with reform is intrinsic to the ideal of higher order thinking. This kind of challenge is therefore not really an attack– it is a valuable part of the process of higher order thinking.
The consensus, supported by research evidence, is that the best way to teach thinking skills is not as a separate subject but through 'infusing' thinking skills into the teaching of content areas.

Brain research is not yet in the position to act as an authoritative support for different teaching and learning strategies. However research findings so far have been suggestive and may well lead to more clear evidence in the future. Of particular interest is the possibility of finding objective correlates for previously rather vague sounding notions such as the expansion of consciousness.

There have been several rigorous surveys of the impact of different teaching methods and programmes in the last decade. These provide convincing evidence for the value of explicitly teaching transferable thinking skills.

convincing evidence for the value of explicitly teaching transferable thinking skills

3 TEACHING THINKING SKILLS WITH TECHNOLOGY

3.1 CONCEPTUALISATIONS OF THE ROLE OF ICT IN EDUCATION

Theories of how the mind works have had a strong effect on the way that the role of new technology has been thought about in education. Surveys of the use of computers to promote thinking skills by both Hughes (1990) and by Underwood and Underwood (1990) draw a sharp distinction between the use of computers as a tutor to teach thinking skills and the use of computers as a tool in order to develop skills indirectly. Crook (1994), in a similar survey, argues that both these ways of conceptualising the role of the computer in relation to thinking skills are inadequate. He develops a third approach which he refers to as the use of computers as a 'mediational means' to 'resource collaborative encounters' (Crook, 1994 p227). These three conceptualisations, computer as tutor, computer as tool or computer as support for dialogue, are reflections of the three main traditions in educational psychology referred to by Greeno, Collins and Resnick and quoted in the first part of this review. I will briefly consider each in turn.

3.1.1 THE COMPUTER AS TUTOR

The behaviourist tradition does not have much to say directly about thinking skills. The language of the movement is mostly about producing observable changes in behaviour. To educate effectively on this model requires a great deal of contingent individual re-inforcement. Computers can provide the individual feedback needed. Skinner was influential in promoting the use of computers as individual teaching machines. Instructional technologists broke down complex tasks into learning hierarchies in order to produce teaching programmes. The current use of Integrated Learning Systems (ILSs) continues in the tradition of the computer as an individual teaching machine. There is evidence that this individualised approach leads to improved learning of some basic skills (Underwood et al 1996).

The main criticism of the computer as a tutor model is that directed computer teaching does not allow children to be creative learners, able to think and make connections for themselves, and so is unlikely to support the development of higher order thinking (e.g. Papert, 1981: Underwood and Underwood, 1990) This criticism assumes constructivism: the claim that knowledge is the product of an active process of construction rather than a passive assimilation of information.

3.1.2 THE COMPUTER AS 'MINDTOOL'

Several popular Science Fiction films show characters 'downloading' skills directly into their brains from computers. The implication is that human skills and computer programmes are very similar. Richard Clark refers to the cause of this popular linking of computers and thinking skills as the reification of a metaphor: the computer metaphor of mind popular in cognitive science (Clark, 1990, p268). When the mind is seen as a kind of computer it seems plausible that working with computers can provide mind skills. Seymour Papert, a student of Piaget, applied constructivism to the role of computers (1981, 1993) advocating the use of programming and other active modelling environments to support learning (where learning was seen as the active construction of meaning). Constructivism is now probably the dominant paradigm in the design of educational multimedia (Boyle, 1996, p83). The implicit idea in much of the literature of cognitivism and constructivism is that the mind is so much like a computer that teaching a computer how to think, i.e. programming, is pretty much the same as learning how to think for oneself. Jonassen (2000) outlines the significance of cognitive psychology and constructivism for the use of technology to promote the development of thinking skills.

Mindtools are computer applications that, when used by learners to represent what they know, necessarily engage them in

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not that computers will directly teach thinking but that, after working in partnership with computers, the student will internalise the way that computers think as a cognitive tool for their own use

critical thinking about the content they are studying. Mindtools scaffold different forms of reasoning about content. That is, they require students to think about what they know in different, meaningful ways. For instance, using databases to organize students' understanding of content organization necessarily engages them in analytical reasoning, where creating an expert system rule base requires them to think about the causal relationships between ideas. Students cannot use Mindtools as learning strategies without thinking deeply about what they are studying. (Jonassen, 1998)

The main idea, also articulated by Underwood and Underwood, (1990) and by Salomon, (1990), is not that computers will directly teach thinking but that, after working in partnership with computers, the student will internalise the way that computers think as a cognitive tool for their own use.

3.1.3 THE COMPUTER AS A SUPPORT FOR LEARNING CONVERSATIONS

Crook (1994, p67) argues that the computer as tutor model and the more constructivist model of computers as support for developing cognitive skills, are both based on similar individualist models of learning. He argues instead for a socio-cultural model of learning which stresses the primacy of the joint construction of knowledge through communication. Within the socio-cultural model, intellectual development is seen as induction into the social practices and the use of the cultural tool-systems through which shared knowledge is constructed. This leads Crook to emphasise the use of the computer as a support and resource for the communicative processes of teaching and learning. Whereas both the computer as tutor model and the computer as tool model encourage the view of the use of computers as a kind of treatment leading to an individual learning outcome, the socio-cultural model argued for by Crook (1994), Newman, Griffin and Cole, (1989), Mercer, (1994) and Saljo (1998) encourages investigation of the way interactive technologies can contribute to learning conversations both in groups and in communities.

I will use these three conceptualisations of the role of ICT in education to structure a review of the way that new technology has been applied to promoting thinking skills

3.2 USES OF COMPUTER AS A TUTOR

It is easy to see how the computer as tutor model can be adapted to teach thinking skills programmes that focus on abstract reasoning and logic puzzles. For example, Riding and Powell (1985) report on a study which used a computer program to tutor 4 year-old children in 'critical thinking skills' using a series of graphical problems. Over the period of the study the children showed improvements in score on a non-verbal reasoning test – Raven's Coloured Progressive Matrices. However the sort of problems that the children were given in the tutorial program were rather similar to the problems in the Raven's reasoning test, leaving Riding and Powell open, as they acknowledge, to the charge of not teaching general skills but of simply training children to perform on a specific test. Follow up studies referred to by Hughes (1990, p125) have shown only very limited transfer to thinking in other contexts. This difficulty in producing transferable skills is to be anticipated from the discussion of thinking skills programmes in general. It is related to the main criticism of the computer as tutor model which is summed up by Papert's complaint that instead of teaching children how to program computers, computers are being used to program children (1980). Both Underwood and Underwood (1990) and Solomon (1987) develop the criticism that directed computer teaching does not allow children to be creative learners able to think and make connections for themselves and so is unlikely to support the development of thinking skills.

Intelligent tutoring systems

'Intelligent Tutoring Systems' ITSs represent a link between the behaviourist approach to Computer Aided Instruction and the cognitivist paradigm. ITSs are a product of Artificial Intelligence research and are said to be intelligent because they embody models of the domain to be learnt, models of students and a model of an expert tutor in the domain. For the most part they remain an expensive tool for AI research with few educational applications. However they are worth mentioning since one idea of ITS has always been to teach thinking skills, such as problem-solving, through modelling them. For example the ITS or expert system can be used to challenge and question students to lead them on the path of problem-solving appropriate to the area. Examples of this kind of feedback might be: 'have you specified all the things that you need to know to make this decision?' 'You appear to have overlooked the patient's heart rate'. 'Have you checked the database for other syndromes that match these symptoms?' and so on.

Diana Laurillard points out that the claims made for ITSs are often overstated. The novel internal architecture of the ITS does not offer any novel pedagogical moves that could not be done in other ways. Despite the name 'intelligent', ITSs seem just like ordinary tutorial systems with a few extra features such as a record of student performance to date and adaptive sequencing of educational activities. But she also claims, more positively, that: 'the ITS is the only medium that can be said to support genuine reflection on the particular learning experience the student has undergone' (Laurillard, 1993 p161) This potential for ITSs, or 'expert systems', in education continues to be explored. Recent approaches include developing 'learning companions' to prompt reflection and guidance to support collaborative learning (Jermann, P, Soller, A., & Muehlenbrock, M., 2001). The idea of using prompts and questions to stimulate reflection and discussion has been applied with some success.

3.3 USES OF MINDTOOLS

3.3.1 PROGRAMMING

Teaching programming has been promoted as a way of learning general thinking skills (Papert, 1980). Perkins and Salomon comment that (1987): 'In general programming is a remarkably rich cognitive enterprise that might yield many different sorts of transfer effects.' (p154). They list some of the possible gains including:

- problem solving, problem finding, and problem management strategies eg breaking a problem into parts or relating it to a previously solved

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problem, planning, and the kind of diagnostic thinking involved in debugging

- abilities of formal reasoning and representation eg thinking of all possible combinations, and constructing mathematical models
- cognitive styles eg precision, and reflectivity over impulsivity
- enthusiasms and tolerances eg persistence, and enthusiasm for meaningful academic engagement.

The logic based programming language LOGO has been widely used in schools and widely evaluated. Results seem equivocal. Simon (1987) surveys a number of evaluations to conclude that Papert's hopes that using LOGO would lead to the emergence of general problem solving skills were 'pipe dreams' and 'techno-romanticism'. Underwood and Underwood's survey of evaluation results is much more positive (1990). Liao and Bright (1991, quoted in Kirkwood, 1998) conducted a meta-analysis of sixty-five classroom based studies into the relationship between computer programming and general cognitive skills, using quantitative comparisons between treatment and control groups. Their main conclusion is that programming can provide a mildly effective approach to developing students' cognitive skills in a classroom setting.

Erik De Corte (1990) demonstrated that using LOGO alone does not produce transfer but that LOGO can be a useful resource in teaching approaches that lead to transfer. The same point is made by Clements and Gullo (1984). Hughes (1990) sums up a balanced survey of the evidence with the following conclusions:

> Exposure to LOGO by itself does not usually lead to cognitive gains; that such gains are more likely to be found with structured teaching; and that the Logo environment promotes social interaction amongst peers. (1990. p133)

3.3.2 VISUALISATIONS AND SIMULATIONS

Some kinds of powerful thinking work through a series of 'leap-frogging' manoeuvres. Scientific thinking, for example, relies on turning processes into nouns so that they can be objectified and thought about more easily (Halliday and Martin, 1993). Representations of every kind allow us to objectify our thoughts so that we can reflect upon them. Writing, graphs, tables and specialist notations such as mathematics are already cognitive tools allowing thought to 'leap-frog' to a higher level of understanding. Computers can take this further through allowing the direct manipulation of representations. Paul Cobb argues that providing computer tools to help students manipulate complex data-sets enables them to understand statistical arguments and therefore equips them to be able to participate in many public debates (2002). Sharon Ainsworth (1997) similarly argues for the value of multiple representations for supporting the development of understanding. Jonassen makes the same kind of case for the use of 'visualisation tools' that allow learners to visualise scientific ideas (Jonassen, 2000). Many simulations of systems play a similar role. They allow users to manipulate dynamic representations of real-world systems.

The literature about using the computer as a tool sometimes blurs the distinction between using external cognitive tools, eg computers, and developing internal cognitive tools, eg thinking skills. These are not the same things. I use a calculator when I change currency, perhaps it is a 'cognitive tool', but that does not mean that I learn how to do long division – I can do long division only because a teacher taught me a pencil and paper technique that I still remember and use. When asked to do long division in the absence of paper and pencil I find myself visualising the numbers and imagining the procedure. I do not find it useful to visualise a calculator and imagine pressing the buttons. If I were a hospital manager funding the development of a computer system to diagnose patients I would want the best system possible, a system that did not need doctors. If, on the other hand, I wanted to help teach medical students the complex skills of diagnosis, involving reasoning, evaluation, information processing and so on, I would want a very different system. I would want the careful 'scaffolding' of skills with the rich presentation of case studies and lots of interactive feedback. Using a computer as a 'mindtool' to solve a problem and learning how to solve it for oneself are therefore different things.

> using a computer as a 'mindtool' to solve a problem and learning how to solve it for oneself are therefore different things

Jonassen claims that the best way to learn about an area is to build a computer system to model the area. From my experience of building computer systems I suspect that in reality far more time would be spent learning how to get the computer tools you were using to do exactly what you wanted than in learning about the area. This is not a very efficient approach to teaching and learning. The evidence suggests that learning skills that can transfer requires someone, usually a teacher, to plan activities and experiences that help to make it happen. There is no good evidence that thinking skills will simply 'rub off' as a 'cognitive residue' (Salomon 1991 quoted in Jonassen, 2000), from using new technology.

The point about 'mindtools', as Jonassen calls them, is that they do not work on their own. To learn from such tools students need to be primed as to what to look for, they need opportunities to articulate what they find and they need feedback on their discoveries. One way of achieving this is to use mindtools as a resource for small group collaborative learning within a teaching and learning framework (Laurillard, 1993 p137: Wegerif, 2002).

> the point about 'mindtools', as Jonassen calls them, is that they do not work on their own. To learn from such tools students need to be primed as to what to look for, they need opportunities to articulate what they find and they need feedback on their discoveries

3.3.3 CONCEPT MAPPING

Concept maps or 'semantic networks' are spatial representations of the concepts and their interrelationships that are intended to represent the knowledge structures that humans store in their minds (Jonassen, 2000). While concept maps do not require computers, computer-based concept-mapping software, such as 'SemNet', 'Learning Tool', 'Inspiration', 'Mind Mapper', and many others, enable the production of concept maps. Great claims are made for the use of concept-mapping as a tool to support critical thinking and reflection on the organisation of knowledge in a subject area while also learning about the area (Buzan and Buzan, 2000: Jonassen, 2000).

The purpose of semantic networks is to represent the structure of knowledge that someone has constructed. So, creating semantic networks requires learners to analyze the structural relationships among

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the content they are studying. By comparing semantic networks created at different points in time, they can also be used as evaluation tools for assessing changes in thinking by learners. (Jonassen 1998)

Concept maps have been used to support inquiry-based science and claims have been made that concept mapping is especially suited to science education. Some research argues that the benefits of concept-mapping can be greatly enhanced if they are used as a focus for collaborative learning (Roth, 1994, Roth and Roychoudhury, 1994)

many people find that concept maps help them to think more clearly about some topics

Diana Laurillard (1993, p123), writing in the context of higher education, is critical of the way in which concept maps reduce knowledge to little chunks of information and defined relationships between them. Knowledge, she argues, is unitary and indivisible.

'even a simple statement such as "as air rises it cools" cannot be expressed as an association between two component fragments'

She is right of course but there is no denying that many people find that concept maps help them to think more clearly about some topics. Educational evaluations of using concept maps mostly seem positive but are small scale (e.g Scanlon et al 1996; van Boxtel et al, 2000).

3.3.4 HYPERTEXT

Hypertext is a 'computer-based software system for organising and storing information to be accessed nonsequentially and constructed collaboratively by authors and users' (Jonassen, 1991, 83). The world wide web is an example of hypertext. There have been very large claims made for the revolutionary nature of hypertext in education. The non-linearity of hypertext is meant to reflect the way that the mind is structured. Reading hypertext involves making a path through it and so is said to be a more constructive process than reading linear print text. External links made between nodes in the hypertext are said to reflect internal semantic links (Jonassen 1998). A review of research on hypertext use in education by Dillon and Gabard (1998 referred to in Bromme and Stahl, 2002) showed no support for the claim that hypertext aides the teaching and learning of thinking skills.

The idea of hypertext is similar to the idea of a library. Those already equipped with effective thinking and learning skills can use libraries as a resource for learning but most students will need more guidance than that. Simply having a library does net mean that you acquire information searching skills.

Bromme and Stahl (2002) argue that, while reading hypertext has few learning benefits, constructing hypertexts is likely to involve thinking skills (2002). Their arguments are similar to those put forward for the value of using concept maps, these are that in developing hypertext documents students need to think about the conceptual structure of an area and reflect on the nature of the links between content.

3.3.5 HYPER-MEDIA

Hyper-media essentially means hypertext with multi-media content. Constructivists, as their name implies, seem very keen on getting children to construct things. Jonassen (2000, p211) argues that making hyper-media products 'allows children to construct their own understandings rather than interpreting the teacher's understanding of the world'. However some engagement with a teacher's understanding is very useful, and often essential, for the learning of new skills. Designing multimedia products, for example web-sites, is clearly a complex process that engages many skills. Carver, Lehrer, Connell, and Ericksen (1992, quoted in Reeves, 1998 and in Jonassen, 2000) list the major thinking skills that learners need as designers of multimedia presentations. These include:

Project Management Skills

- creating a timeline for the completion of the project
- allocating resources and time to different parts of the project
- assigning roles to team members.

Research Skills

- determining the nature of the problem and how research should be organized
- posing thoughtful questions about structure, models, cases, values, and roles
- searching for information using text, electronic, and pictorial information sources
- developing new information with interviews, questionnaires and other survey methods
- analyzing and interpreting all the information collected to identify and interpret patterns.

Organization and Representation Skills

- deciding how to segment and sequence information to make it understandable
- deciding how information will be represented (text, pictures, movies, audio, etc.)
- deciding how the information will be organized (hierarchy, sequence) and how it will be linked.

Presentation Skills

- mapping the design onto the presentation and implementing the ideas in multimedia
- attracting and maintaining the interests of the intended audiences.

Reflection Skills

- evaluating the program and the process used to create it
- revising the design of the program using feedback.

That all sounds plausible but could not all of these skills equally be developed through designing and making a poster display? While, with the right pedagogy, designing multi-media could support the teaching of thinking skills, it is not obviously the easiest or the cheapest way to do this.

no support for the claim that hypertext aides the teaching and learning of thinking skills

3.3.6 COMPUTER GAMES

Whitebread (1997) claims that playing computer games can help develop thinking skills. Even a game such as Lemmings, often considered purely as an entertainment game, he claims has the potential to develop skills such as:

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there is no evidence that games, or any other software for that matter, can teach thinking skills on their own

- understanding and representing the problem (including identifying what kinds of information are relevant to its solution)
- gathering and organising relevant information
- constructing and managing a plan of action, or a strategy
- reasoning, hypothesis-testing and decision-making
- using various problem-solving tools (p17).

'The Logical Journey of the Zoombinis', has been evaluated very highly by Steve Higgins for its capacity to promote logical reasoning skills when integrated with the right pedagogy (Higgins, 2000). This software was developed by a university team in collaboration with Broderbund.

Collaboration around games seems to have a positive effect on problem-solving. Inkpen et al (1995) found that when children played 'The Incredible Machine' (TIM), a problem-solving game, together on one machine, they 'solved significantly more puzzles than children playing alone on one machine'. They were also more motivated to continue playing when they had a human partner.

There is no evidence that games, or any other software for that matter, can teach thinking skills on their own. They can be used as a resource to help teach thinking within a pedagogical framework.

3.4 COMPUTER AS A SUPPORT FOR LEARNING CONVERSATIONS

Much work in the area of computer supported collaborative learning focuses on improving the medium of shared or social thinking rather than upon directly promoting individual thinking skills. However, as I argued in part two of this review, higher order thinking is both a social and an individual activity. Promoting engagement in higher order collective thinking is also a way to teach thinking skills.

3.4.1 COLLABORATIVE LEARNING

Teasley and Roschelle (1993) report a study that illustrates the role of computers in supporting collaborative learning and thinking. Their study concerned pairs of learners using a simulation designed to teach Newtonian physics, called the 'Envisioning Machine'. In it they argue that the essential medium of the learning is the talk between the learners and that the role of the computer lies in supporting that talk and resourcing their collaboration (ibid. p254). The computer screen offers a shared focus, a means to 'disambiguate' language through images on the screen, and a means to resolve conflicts by testing out alternative views. Teasley and Roschelle write:

> We see the 'computer-supported' contribution to collaborative learning as contributing a resource that mediates collaboration. In ordinary circumstances one cannot imagine two 15-year-olds sitting down for 45 minutes to construct a rich shared understanding of velocity and acceleration. But in the context provided by the Envisioning Machine activity, our students were successful in doing just that. (ibid. p254)

This conceptualisation of the educational role of the computer as a medium supporting collaborative learning is the view which is most in accord with the sociocultural theoretical framework. Teasley and Roschelle argue that it throws the emphasis away from the computer software and on to the quality of the dialogue.

Further evidence that the pedagogy is as important as the technology comes from my own work with Neil Mercer, Lyn Dawes and Karen Littleton at the Open University. In this research an approach has been developed using computers that prepares children to work effectively together with specially-designed computer-based activities focused on curriculum-related topics. A series of 'Talk Lessons' are followed, in which classes establish ground-rules for collaboration such as listening with respect, responding to challenges with reasons, encouraging partners to give their views and trying to reach agreement. These activities are not only concerned with improving the quality of children's working relationships, but also with developing their use of language as a tool for reasoning and constructing knowledge. That is, the Talk Lessons encourage teachers to create a 'community of enquiry' in their classrooms in which children are guided in their use of language as a tool for both individual reasoning and collaborative problem-solving. Computers are used not only for stimulating effective language use but also for focusing children's joint activity on curriculum tasks. This embedded and catalytic role for computers in primary education is distinctive (Wegerif, 1996b: Wegerif and Scrimshaw, 1997; Wegerif, Mercer and Dawes, 1998: Wegerif, Sams and Barrett, 2002: Wegerif and Dawes, 2003).

In the most recent study of this approach we developed ICT activities in Maths and Science to cover an entire year of the curriculum. Our evaluation demonstrated that computer-based activities can be used to stimulate reasoned discussion and focus this on curriculum-related learning. We used a control study to demonstrate significant gains in scores on curriculum tests in Science and Maths. We also found significant improvements in solving reasoning test problems when working together in small groups. Video analysis has demonstrated a link between solving such problems and use of 'exploratory talk' (Wegerif and Mercer, 2000). This effect also transferred to significant improvements in individual scores on Ravens Progressive Matrices tests. Higgins (2001) argues that the findings of this research offer persuasive evidence that, in combination with the right pedagogy, the use of ICT can support the development of transferable thinking skills.

3.4.2 CONFERENCING

There are many claims that electronic conferencing can be an effective support for learning thinking skills through collaborative learning. Such claims can be found in Mason (1989), McConnell (1995) and Harasim et al (1995). At least some of the factors claimed to support reasoning relate to the specific way in which the medium supports discourse. For example:

- the ease with which it is possible to 'take the floor' in a discussion in comparison with face-to-face discussion
- the possibility of having several strands of conversation simultaneously supports more meta-cognitive reflection

this embedded and catalytic role for computers in primary education is distinctive

with the right pedagogy these kind of resources could be used to help to understand classification and to think more about the relationships between categories

- the written nature of the dialogue combined with asynchronicity can allow time for refection while maintaining the intrinsic motivation of a conversation. (Wegerif, 1998)

These differences between CMC communication and face-to-face communication have been pointed out by David Graddol (1989) and are reiterated by David McConnell (1994) . The conclusion from both these writers appears to be that CMC can support an egalitarian style of communication in which everyone can participate more easily. One possible implication of this is that CMC might be a good medium for establishing what Habermas (1981) calls an 'ideal speech situation': that situation which, through the elimination of all forms of coercion and through ground rules allowing all to speak, best supports the force of good arguments winning out over other, less rational, factors. However, others have claimed, by contrast, that the medium is particularly prone to aggression and irrationality (Siegal,Dubrovsky, Kiesler and McGuire, 1986 quoted in Jonassen, 2000, 265). Laurillard's claim that 'the success of the medium is totally dependent on a good moderator' (1993 p169) is therefore probably a fair assessment of the situation.

Links via email or electronic conference with other schools can be used for the joint construction of knowledge including critical questioning and reasoning.
An example might be taking a particular topic to research together in order to develop joint multi-media resources on the web. This approach is found in Margaret Riel's 'circles of learning' (Riel, 1996).

3.4.3 THE INTERNET

Steve Higgins (2002) draws a distinction between thinking through and thinking with the internet. As an example of the former he suggests 'Newswise', (http://www.dialogueworks.co.uk/) an internet resource aimed at primary and secondary pupils which offers access to appropriate texts for discussion, a forum for exchanging ideas and support for teachers in developing strategies to help engage their pupils in different aspects of the stories and texts. This uses the internet as a medium for exchanging news stories (accessed by teachers and pupils) and exchanging ideas about those stories. The same principle is found in OneWorldTV (http://tv.oneworld.net/) where video news stories are presented and debated by a global audience.

By 'thinking with the internet' Higgins means using the internet itself as the tool (rather that just the medium of communication). For example using html with hotspots and links to create non-linear texts or pictures and diagrams that can be explored to support teaching and learning. The interactive relationship with information can be used to promote thinking skills. The search engine Kartoo, for example, offers visual results and shows the results of its metasearch with sites being interconnected by keywords. (http://kartoo.com). With the right pedagogy these kind of resources could be used to help to understand classification and to think more about the relationships between categories.

3.4.4 SHARED DATABASES

CSILE, which stands for Computer Supported Intentional Learning Environments (Scardemalia et al, 1991: 1994), consists of a number of networked computers in a classroom where a community database is maintained. The database consists of text and graphical notes, all produced by students and accessible through database search procedures. Teachers work with CSILE in different areas of the curriculum. Students are given a question, they have to find information and record it via notes in the database. Other students then comment on the notes and add new notes.

Evaluations of learning outcomes in CSILE classrooms are positive and reflect the development of thinking skills, including great comprehension of texts and deeper explanations of processes as well as the development of a more positive self-image as learners.

3.5 HOW TO TEACH THINKING WITH ICT

3.5.1 UNDERSTANDING EVALUATIONS OF THE RESEARCH

Reeves, (1998) quotes many positive effects of technology use in education including learning thinking skills. These findings in the USA have been matched more recently in the UK by the DfES Impact2 study (2002b). One problem with these evaluations, and others mentioned in this section of the report, is that all interventions seem to work. Enthusiastic researchers who believe in their proposed solutions can motivate teachers and children regardless of the content of the intervention. More positively, integrating new technology is often a chance for teachers to re-think their approach. There is evidence that new technology often works in this way as a catalyst for change. A particular problem with evaluating the effects of technology is that such effects depend completely on how the technology is used. The quality of an educational activity is not an effect of the software alone but of the software in context. The same piece of software might have quite different effects if used in different pedagogical contexts. Teachers (or parents or moderators) play a crucial role in setting up and guiding any learning experience with ICT.

Many claims in this area need to be treated with caution. There are evidently many enthusiasts who love to see children having fun playing with computer-based toys and games and making wonderful multi-media products. The important question is not 'do they display thinking skills in what they are doing? Of course they do. A better question is: 'is there any evidence that these skills will transfer in a useful way to other contexts in their lives?'

3.5.2 THE PEDAGOGICAL CONTEXT

The research evidence seems to suggest that transferable thinking skills will not result unless activities are embedded in teaching and learning dialogues, either with a teacher or with other students. In other words the activity, however creative or fun, needs to be framed in such a way that learning goals are made explicit and bridges are built between contexts.
This suggests a need for developers to consider the context of use of any ICT and to provide support for using it in a way that will lead to transferable thinking skills.
Out of his experiments with different ways

the quality of an educational activity is not an effect of the software alone but of the software in context

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of teaching with LOGO described above, De Corte (1990) proposed the following features of powerful learning environments:

- learners need an explicit explanation of the cognitive components of the task (a 'thinking' vocabulary)
- learners need to observe an expert performing the task (modelling)
- learners need to be given hints and feedback on their own performance (coaching)
- learners need to be given direct support in the early stages of learning a task (scaffolding) and to move gradually towards self-regulation and autonomy (teacher-fading)
- learners need the opportunity to articulate their cognitive and metacognitive strategies and to make comparisons with other learners (reflection)
- learners need to explore, identify and define new problems in a domain and be shown how strategies acquired in one domain can be used to solve problems in another domain (transfer).

While group or paired work is not essential for learning thinking skills with ICT all the evidence suggests that it helps. Having to articulate and explain strategies to others is far more likely to lead to transfer than just doing things without verbalisation. However there is plenty of evidence that just putting children in front of a screen and asking them to work together is not sufficient (e.g. Dawes, 1997). The best approach is to teach children how to work together effectively before they are asked to work at the ICT task (Dawes, Mercer and Wegerif, 2000).

Another effective strategy used by the 'Thinking Together' approach (Moseley et al, 1999) is a three-part structure to ICT activities. The teacher sets up issues and aims at the beginning and then returns to these in a whole group plenary session at the end after group work by the children. The teacher needs to be explicit about thinking skills aims at the beginning of the lesson – to point out that work with LOGO, for example, is not just about playing but is also about reasoning together to develop effective strategies - and then to visit these aims again at the end of the lesson. In the plenary the teacher needs to draw out what has been learnt and how this could be applied elsewhere. Linking activities showing how similar kinds of thinking skills can be applied in different areas of the curriculum is also a good idea. In this case again explicit bridges need to be made at the beginning and the end of each activity.

3.5.3 ICT DESIGN

Using computers as tutors can be an effective way of infusing thinking skills into subject area teaching and learning. This is because, with the right teacher input and software design group work around computers can turn the use of reasoning skills into learning outcomes. Software can be designed to initiate, resource and frame a discussion just as a teacher can, but unlike teachers they are never judgmental and have infinite patience. Once learners have been prepared for group work by a teacher or by the ethos of a social setting, then when the computer prompts them with a challenge or a question they are able to sit back from the screen and discuss the issue together before reaching a shared decision about what response to make. In this way they can construct their own understandings together, but in a way that is directed towards curriculum goals by the computer software. Research analysing video-tapes of pairs and small groups of children working around computers has given us some clues as to what software features help to establish and sustain effective talk:

- challenges and problems which have meaning for the children, and which provide a range of alternative choices that are worth discussing. Such challenges should engage the learners with the content of the software rather than its interface
- a clear purpose or task which is made evident to the group and which is kept in focus throughout
- on-screen talk prompts which ask the group to talk together, remind them to reach agreement and ask for opinions and reasons
- resources for discussion, including information on which decisions can be based and opportunities to review decisions in the light of new information
- no features which encourage individuals to take turns, beat the clock or establish competitive ways of working
- audio input or multi-choice answers to minimise typing (unless the learners have keyboarding skills). (adapted from Wegerif, 1997)

These guidelines can be used as a basis for designing software or for selecting software that can be used to support collaborative learning.

ICT is distinct from other educational technologies in that it has the capacity to represent ideas and information in easily changed, multiple and dynamic forms. Data-bases, graphs and concept-mapping can all be used to support critical and analytical thinking about relationships within an area, as well as to bring out patterns that unite different areas. CSILE has shown that building up shared data-bases can be an effective way of teaching and applying thinking skills. Links via email or electronic conference with other schools can be used in similar ways for the joint construction of knowledge including critical questioning and reasoning. Tools to support collective higher order thinking using these media need to be designed in. These could range from the kind of templates or forms used in CSILE, through symbolic languages, through to prompts for reflection.

ICT is distinct from other educational technologies in that it has the capacity to represent ideas and information in easily changed, multiple and dynamic forms

3.6 SUMMARY OF SECTION 3

The three main approaches to understanding learning that were introduced in part one were applied to understand different ways in which the role of ICT in supporting learning has been conceptualised. Behaviourism was linked to the use of the computer as a teaching machine, cognitivism/constructivism to the use of ICT as a tool and the socio-cultural/participationist school to the use of ICT as a support for learning conversations. These three conceptualisations, ICT as tutor, tool or support for dialogue, were used to structure a review of examples of ICT used to teach thinking skills.

One of the first principles to emerge from these studies was that the computer-based technology alone does not lead to transferable thinking skills. Whether the ICT is conceptualised as tutor, tool or support for communication, the success

IMPLICATIONS FOR PRACTICE, CURRICULUM DEVELOPMENT AND THE DESIGN OF LEARNING RESOURCES

learners need to know what the thinking skills are that they are learning and these need to be explicitly modelled, drawn out and re-applied in different contexts

of the activity crucially depends on how it is framed. Learners need to know what the thinking skills are that they are learning and these need to be explicitly modelled, drawn out and re-applied in different contexts.

Effective teaching for transferable thinking skills with ICT contains some or all of the following elements:

- teaching a 'thinking' vocabulary and giving learners an explicit explanation of the thinking skills that they are to be learnt
- observing an expert performing the task (modelling)
- giving timely feedback on performance (formative assessment)
- direct support in the early stages of learning a task (scaffolding) and then a gradual move towards self-regulation and autonomy (teacher fade-out)
- the opportunity to articulate thinking strategies and discuss these with other learners (thinking together)
- the explicit demonstration of how thinking strategies acquired in one subject area can be used to solve problems in another area (bridging).

Another principle to emerge was that collaborative learning improved the effectiveness of most activities. Where tutorial software alone is ineffective for developing thinking skills, tutorial software used as a basis for discussion between learners can be. Computer mind-tools, such as concept maps or programming languages, all appear to be enhanced when used in pairs or groups who are taught to explicitly articulate their strategies as they work together. This is interesting because most software is still designed for individual work, in many cases it could easily be re-designed to support collaboration.

Three ways in which the use of ICT could particularly enhance the teaching and learning of thinking skills emerged: First, thinking skills can be developed by supporting dynamic and multiple representations of information. Visualising patterns in data-sets, for example, allows learners to think at a higher level about statistical relationships.

Second, through a certain ambivalence of nature, educational software can act like a teacher to prompt and direct enquiry but can, at the same time, act as a resource while learners discuss and explore ideas. Prompting reflection around a simulation could be an example.

Third, networks can allow students to engage directly in knowledge creation with others who are not physically present. Given the apparent importance of collaborative learning this has significance for home education. And while it is not intrinsically superior to think together with those outside the classroom, than with those within, it can be more motivating. If those outside the classroom, have a different perspective on issues it can also stimulate more thought.

4 IMPLICATIONS FOR PRACTICE, CURRICULUM DEVELOPMENT AND THE DESIGN OF LEARNING RESOURCES

4.1 IMPLICATIONS FOR PRACTICE

The use of technology alone does not lead to transferable thinking skills. The success of any educational activity crucially depends on how it is framed. Learners need to know what the thinking skills are that they are learning and these need to be explicitly modelled, drawn out and re-applied in different contexts.

A simple but effective strategy is to use a three-part structure to ICT activities. The teacher sets up issues and aims at the beginning and then returns to these in a whole group plenary session at the end after group work by the children. The teacher needs to be explicit about thinking skills aims at the beginning of the lesson, modelling the use of the skills being taught, and then these aims need to be visited again at the end of the lesson. In the plenary the teacher needs to draw out what has been learnt and how this could be applied elsewhere. Explicitly linking to further activities that show how similar kinds of thinking skills can be applied in different areas of the curriculum is also a good idea. Explicit links (bridges) to thinking skills need to be made at the beginning and the end of each activity in which the thinking skill is meant to be applied.

4.2 IMPLICATIONS FOR CURRICULUM DEVELOPMENT

Effective teaching for transferable thinking skills with ICT contains some or all of the following elements:

- teaching a 'thinking' vocabulary and giving learners an explicit explanation of the thinking skills that are to be learnt
- observing an expert performing the task (modelling)
- giving timely feedback on performance (formative assessment)
- direct support in the early stages of learning a task (scaffolding) and then a gradual move towards self-regulation and autonomy (teacher fade-out)
- the opportunity to articulate thinking strategies and discuss these with other learners (thinking together)
- the explicit demonstration of how thinking strategies acquired in one subject area can be used to solve problems in another area (bridging).

Collaboration around ICT activities has been shown to have the potential to enhance the learning of transferable thinking skills. However effective collaborative learning needs to be prepared. It helps if learners are explicitly taught how to reason and learn together before they are asked to work collaboratively with ICT.

4.3 IMPLICATIONS FOR THE DESIGN OF LEARNING RESOURCES

The best software for teaching thinking skills comes from collaborations between developers and educators or educational researchers.

Some of the guidelines for the effective teaching for thinking skills could be incorporated into software design. For example, being explicit about thinking skills, modelling them, designing activities that use the same skills in different context and prompting learners to reflect on thinking strategies and articulate them clearly.

Software can be designed to initiate, resource and frame a discussion just as a teacher can, but unlike teachers they are

explicit links (bridges) to thinking skills need to be made at the beginning and the end of each activity in which the thinking skill is meant to be applied

IMPLICATIONS FOR PRACTICE, CURRICULUM DEVELOPMENT AND THE DESIGN OF LEARNING RESOURCES

learners can construct their own understandings together but in a way that is directed towards curriculum goals by the computer software

never judgmental and have infinite patience. In this way learners can construct their own understandings together but in a way that is directed towards curriculum goals by the computer software. An example of this is to incorporate prompts for discussion around a simulation. Before running a simulation the prompt could be: 'what is your prediction?' And afterwards: 'can you explain why you were right/wrong?'

ICT has a particular role to play through supporting dynamic and multiple representations of information. Visualising patterns in data-sets, for example, allows learners to think at a higher level about statistical relationships.

Networks can allow students to engage directly in knowledge creation with others who are not physically present. Given the apparent importance of collaborative learning this has significance for home education. And while it is not intrinsically superior to think together with those outside the classroom than with those within, it can be more motivating. If those outside the classroom have a different perspective on issues it can also stimulate more thought.

Building up shared data-bases can be an effective way of teaching and applying thinking skills. Links via email or electronic conference with other schools can be used in similar ways for the joint construction of knowledge, including critical questioning and reasoning. These forms of collaborative knowledge-construction could be supported by in-built supports for thinking.

Much of the software that has been called 'mindtools', such as concept maps and hypertext authoring environments, has potential to support the development of thinking skills with the right pedagogy. The pedagogy needs to frame individual discoveries within teaching and learning conversations. Collaboration between learners, for example, has been shown to enhance the learning of thinking skills using so called mindtools partly because it encourages the explicit articulation of thinking strategies.

The finding about the value of collaborative learning is interesting for designers since most software is obviously intended for individual use. There are several simple ways of designing software to support collaboration.

- challenges and problems which have meaning for the learner, and which provide a range of alternative choices that are worth discussing. Such challenges should engage the learners with the content of the software rather than its interface
- a clear purpose or task which is made evident to the group and which is kept in focus throughout
- on-screen talk prompts which ask the pair or group to talk together, remind them to reach agreement and ask for opinions and reasons
- resources for discussion, including information on which decisions can be based, and opportunities to review decisions in the light of new information
- no features which encourage individuals to take turns, beat the clock or establish competitive ways of working
- clicking, multi-choice answers or audio input to minimise typing (unless the learners have been taught keyboarding skills).

GLOSSARY

bloom's taxonomy popular instructional model developed by the prominent educator Benjamin Bloom. It categorises thinking skills from the concrete to the abstract-knowledge, comprehension, application, analysis, synthesis, evaluation. The last three are considered **higher-order** skills.

cognition the mental operations involved in thinking; the biological/neurological processes of the brain that facilitate thought.

creative thinking imaginative activity fashioned so as to produce outcomes that are both original and of value. (NACCE (1999).

critical thinking the process of determining the authenticity, accuracy, or value of something; characterised by the ability to seek reasons and alternatives, perceive the total situation, and change one's view based on evidence. Also called 'logical' thinking and 'analytical' thinking.

dialogue shared enquiry.

dialogic informed by more than one voice or perspective – the 'interanimation' of more than one voice or perspective.

infusion integrating thinking skills instruction into the regular curriculum; infused programs are commonly contrasted to **separate** programs, which teach thinking skills as a curriculum in itself.

metacognition the process of planning, assessing, and monitoring one's own thinking.

thinking skills 'thinking skills' and related terms are used to indicate a desire to teach processes of thinking and learning that can be used in a wide range of real-life contexts. The list of thinking skills in the English National Curriculum is similar to many such lists: information-processing, reasoning, enquiry, creative thinking and evaluation.

transfer taking something, an idea or skill, that has been learnt in one context and applying it in a different context.

INTERNET LINKS

(Adapted from the MAPE Pack: Focus on ICT and Thinking, Prepared by Steve Higgins. 2002)

Website addresses change regularly. If any of the addresses below are no longer valid try a search for the name of the organisation or the resource.

Interest in the UK in thinking skills has increased as a result of its inclusion in the National Curriculum. The following web site (on the National Curriculum site) lets you do a search for thinking skills objectives in the national curriculum by type of thinking, subject and key stage. http://www.nc.uk.net/LACcs_thinkskill.html

Sites and Information about Specific Thinking Skills Programmes

There are a growing number of sites about Philosophy for Children (P4C) and the Community of Enquiry such as Matthew Lipman's site the Institute For The Advancement of Philosophy For Children based at Montclair State University-Matthew Lipman's site (http://chss.montclair.edu/iapc/homepage.html) with links to the Institute for Critical Thinking (http://www.chss.montclair.edu/ict/homepage.html).

The Society for the Advancement of Philosophical Enquiry and Reflection in Education (http://www.sapere.net/) is a UK based educational charity offering resources, conferences, and training in philosophy for children. A good starting point for further P4C links is Terry Godfrey's W3P4C site (http://www.p4c.net/). For an international flavour of the movement have a look at some of the links to work across the globe such as the Federation of Australian Philosophy for Children Associations (http://www.utas.edu.au/docs/humsoc/philosophy/postgrads/FAPCA.html) and the Argentinian branch of Philosophy for Children (http://www.izar.net/fpn-argentina/).

Reuven Feuerstein's International Centre for the Enhancement of Learning Potential (ICELP) has its own website (http://icelp.org/Pages/What_is_IE.htm). There are links to examples of the 'instruments'. A good overview of his programme of Instrumental Enrichment can be found on North West Regional Educational Laboratory's web site which evaluates a range of school improvement programmes (http://www.nwrel.org/scpd/natspec/catalog/feuerstein.htm) used in the US.

Edward de Bono's catalogue of resources (such as CoRT and the Thinking Hats) is on-line and colour-coded like his thinking hats (http://www.edwdebono.co.uk/debono/home.htm).

Top Ten Thinking Tactics - has brief information from the publisher (http://www.education-quest.com/catalogue/- click on the 'Thinking Skills' link) about this programme, together with other thinking skills books and resources. Alistair Smith's Accelerated Learning has its own web site (http://www.alite.co.uk/) as does Robert Fisher (http://www.teachingthinking.net/).

Kings College London have developed two thinking skills programmes CASE (Cognitive Acceleration Through Science Education) and CAME (Cognitive Acceleration Through Maths Education). These are aimed at secondary schools, though being developed for younger pupils. Information about CASE can be found at: http://www.kcl.ac.uk/depsta/education/teaching/CASE.html. And CAME similarly at: http://www.kcl.ac.uk/depsta/education/teaching/CAME.html.

Readings and Research about Teaching Thinking

Teaching Thinking: an Introduction to the Research Literature is a paper by John Nisbet originally published in 1988 available on the web (http://www.scre.ac.uk/spotlight/spotlight26.html). It is part of the Scottish Council for Research in Education (SCRE) Spotlights series - worth checking out in its own right. Other relevant Spotlights are number 79 "Can thinking skills be taught", by Valerie Wilson (http://www.scre.ac.uk/spotlight/spotlight79.html) and number 82 "Peer and Parent Assisted Learning in Reading, Writing, Spelling and Thinking Skills" by Keith Topping (http://www.scre.ac.uk/spotlight/spotlight82.html).

Teaching Thinking magazine (http://www.teachthinking.com/), from Questions publishing, has a research section and accessible articles. You have to subscribe to get full access.

An ERIC digest about teaching thinking is also available, though a little dated now (http://www.ed.gov/databases/ERIC_Digests/ed385606.html).

Teaching Thinking Skills by Kathleen Cotton, (http://www.nwrel.org/scpd/sirs/6/cu11.html) is another entry in School Improvement Research Series at Northwestern University with information on a number of approaches.

The Information Literacy Place is Sheila Webber and Bill Johnston's collection of useful information literacy resources.

Web resources for teachers and pupils

Northumberland LEA's Thinking for Learning (http://ngfl.northumberland.gov.uk/) site has teaching thinking resources developed by teachers using many of the strategies in this book.

The Thinking Together site (http://www.thinkingtogether.org.uk/) has resources linked to the articles in this review and the book of the same name by Lyn Dawes, Neil Mercer and Rupert Wegerif.

Dialogue Works (http://www.dialogueworks.co.uk/) produce Newswise, an on-line resource to promote thinking through news stories and Storywise a handbook by Karen Murris and Joanna Haynes for developing Community of Enquiry with young children. This is the updated version of 'Teaching Philosophy with Picture Books' which inspired us to try out the community of enquiry with younger pupils in schools.

There are many other sources of information if you search on the Internet. Try terms like 'critical thinking' (which is often used in the US) as well as 'thinking skills'. There is no guarantee you will find what you want, but a search can provide useful results.

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REPORT 2

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