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RESEARCH REPORT

From the general to the situated: three decades of metacognition

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This paper discusses the notion of metacognition, which is usually defined as 'cognitions about cognitions', or 'thinking about one's own thinking'. In so doing, it reviews the literature on metacognition over the past three decades, listing different definitions of the term and identifying diverse origins of processes metacognitive. Aspects of the nature of metacognition are discussed, highlighting some of its important yet problematic dimensions, and the potentially positive impact metacognition can have on the learning process is addressed. The paper also relates metacognition to the broader area of general thinking skills and discusses the appropriateness of practising metacognition with primary school children. The paper concludes with a synopsis of research in the outcomes of metacognition, in general, and in science education, in particular, highlighting recent interest in blending metacognitive thinking with science subject matter. Directions for research in science education with an interest in metacognition are also proposed.

Introduction

> . . . if somebody knows something, then he knows that he knows it, and at the same time he knows that he knows that he knows. (Spinoza 1632–1677)

The term 'metacognition' was introduced by John Flavell in the early 1970s based on the term 'metamemory' previously conceived by the same scholar (Flavell 1971). Flavell (1979) viewed metacognition as learners' knowledge of their own cognition, defining it as 'knowledge and cognition about cognitive phenomena' (p. 906). Metacognition is often referred to in the literature as 'thinking about one's own thinking', or as 'cognitions about cognitions'. It is usually related to learners' knowledge, awareness and control of the processes by which they learn (Brown 1987, Garner and Alexander 1989, Thomas et al.), and the metacognitive learner is thought to be characterized by ability to recognize, evaluate and, where needed, reconstruct existing ideas (Gunstone 1991). Flavell's definition was followed by numerous others, often portraying different emphases on (or different understanding of) mechanisms and processes associated with metacognition. Paris and his colleagues, for example (Paris and Jacobs 1984, Cross and Paris 1988, Paris and Winograd 1990), identified two essential features in their definition of metacognition: 'self-appraisal' and 'self-management' of cognition. Self-appraisal of cognitions comprises reflections about learners' understanding, abilities and affective state during the learning process, while self-management refers to 'metacognitions in action'; that is, mental processes that help to 'orchestrate aspects of problem solving' (Paris and Winograd 1990: 8).

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'Metalearning' (White and Gunstone 1989), 'deutero-learning' (Bateson 1983) and 'mindfulness' (Salomon and Globerson 1987) are terms also used in the literature to describe an awareness of problems, situations, and ways of thinking and talking about them. The number of definitions, terms and analyses of what metacognition stands for has been the cause for some confusion in the literature. Weinert (1987), for instance, spoke of a 'vague' and 'imprecise' working definition of metacognition. Adey and Shayer (1994), on the contrary, referred to confusion among science educators over not only the meaning of the term 'metacognition', but also its actual recognition. Since the introduction of the term by Flavell, 'metas' (e.g. 'metalistening', 'metacommunication', 'metapersuasion') have proliferated in the literature (Kluwe 1987). Watts (1998), for instance, argued that very close to the notion of metacognition stands 'meta-affection' that focuses on the affective dimension of learning, defining this as 'the conscious awareness, monitoring, regulation and evaluation of intra-personal and interpersonal affective activity' (p. 8). Interestingly, all processes referred to in the definition of 'meta-affection' are either initiated or controlled by cognitive mechanisms, suggesting the strong dependence of anything 'meta' on cognitive functions.

The importance and origins of metacognition

Relating metacognition to developing one's self-knowledge and ability to 'learn how to learn' resulted in metacognition being awarded a high status as a feature of learning. The ground for developing such an interest proved particularly fertile, especially in view of a constantly changing technological world when not only it is impossible for individuals to acquire all existing knowledge, but it is also difficult to envisage what knowledge will be essential for the future. The subsequent calling for inclusion of metacognition in the development of school curricula, therefore, seems fully justified. Flavell (1987) proposed that good schools should be 'hotbeds of metacognitive development' because of the opportunities they offer for self-conscious learning. Similarly, Paris and Winograd (1990) have argued that students' learning can be enhanced by becoming aware of their own thinking as they read, write, and solve problems in school, and that teachers should promote this awareness directly by informing their students about effective problem-solving strategies and discussing cognitive and motivational characteristics of thinking. Clearly sharing this view, Gunstone and Northfield (1994) took a step further and argued in favour of a central position of metacognitive instruction within teacher education. Borkowski and Muthukrishna (1992) similarly have argued that metacognitive theory has considerable potential for aiding teachers in their efforts to construct classroom environments that focus on flexible and creative strategic learning. Voices advocating the importance of metacognitive activity within educational contexts have resulted in placing metacognition high on educational research agendas.

Reasons for the growing interest in metacognition over the past three decades relate not only to the anticipated improvement in learning outcomes, through interventions that aim at developing students' metacognition, but also to the broader rise in interest in cognitive theories of learning. However, as Brown (1987) points out in a review of the origins of metacognition, 'processes metacognitive' have been recognized and advocated by educational psychologists (for example, Dewey 1910, Thorndike 1914) well before the emergence of the term 'metacognition', especially in the area of reading and writing. John Locke, for instance, used the term 'reflection' to refer to the 'perception of the state of our own minds' or 'the notice which the mind takes of its own operations' (Locke 1924). The importance of the concept of reflected abstraction to human intelligence was later discussed by Piaget (1976), who pointed out the need for making cognitions statable and available to consciousness, at which point they can be worked on and further extended (Campione 1987). Notably, the work of Piaget was introduced to many in the US by John Flavell (1963), maintaining a profound impact on Flavell's writings and the development of his notion of metacognition. 'Introspection', a technique used by early psychologists to find answers to psychological questions, was also a first sign of interest in metacognitive processes. The definition of 'introspection' as 'the reflection on one's own conscious experience' (Butler and McManus 1998: 4) makes such connection all too obvious.

In searching for the origins of metacognition others go far beyond the twentieth century. As Spearman points out:

> Such a cognizing of cognition itself was already announced by Plato. Aristotle likewise posited a separate power whereby, over and above actually seeing and hearing, the psyche becomes aware of doing so. Later authors, as Strato, Galen Alexander of Aphrodisias, and in particular Plotinus, amplified the doctrine, designating the processes of cognizing one's own cognition by several specific names. Much later, especial stress was laid on this power of 'reflection', as it was now called by Locke. (1923: 52–53)

Hard as it might be to pinpoint the exact origins of metacognition, it is by far easier to reach agreement over the fact that recent attention in metacognition has resulted in the reawakening of interest in the role of consciousness, awareness or understanding in thinking and problem-solving (Campione 1987).

Following a review of the many different historical roots from which metacognition has developed, Brown (1987) warned that '. . . metacognition is not only a monster of obscure parentage, but a many-headed monster at that' (p. 105). The acknowledged complexity of the notion of metacognition is also successfully reflected in Flavell's (1987) remark that although metacognition is usually defined as knowledge and cognition about cognitive objects (i.e. about anything cognitive), the concept could reasonably be broadened to include anything psychological, rather than just anything cognitive. In his attempt to identify where metacognition fits in 'psychological space' Flavell (1987) suggested that concepts that may be related to metacognition include executive processes, formal operations, consciousness, social cognition, self-efficacy, self-regulation, reflective self-awareness, and the concept of psychological self or psychological subject. The diversity of perceived meaning and the multidimensional nature of metacognition are therefore without question, a conclusion that was reached by numerous studies in the past, and is discussed later in this paper. Before discussing further aspects of the nature of metacognition, it is important to address briefly the area of general thinking skills, which shares important links with metacognition.

General thinking skills

Emphasis on the teaching of general thinking skills was a prevailing feature of western educational systems of the post-Sputnick era viewed by politicians, policy-makers and academics as the way ahead for reforming and boosting the failing education of that time. Typical of the importance attributed to developing ability to think is the statement made by the Educational Policies Commission in the US in 1961, assuming that:

> The purpose which runs through and strengthens all other educational purposes – the common thread of education – is the development of the ability to think. This is the central purpose to which the schools must be oriented . . . the development of every student's rational powers must be recognized as centrally important. (Educational Policies Commission 1961: xiv)

Interest in improving learners' thinking skills, however, goes back far beyond the 1960s, being interpreted by some as a response to the indoctrinating nature of much of organized schooling (Costello 2000). Alfred Binet, for instance, who is most widely known for devising the first mental tests, later to be known as IQ tests, believed that children's intellectual performance could be improved. He proposed a training system he called 'mental orthopaedics' aiming towards strengthening a variety of thinking skills including attention, memory, perception, invention, analysis, judgement and will. The apparent trend of developing thinking skills that emerged in recent years has followed mainly three different approaches: (a) teaching general thinking skills, (b) teaching subject-specific (or domain-specific) thinking skills (e.g. in science, mathematics), and (c) teaching thinking skills across the curriculum. Regardless of the approach followed, most scholars assume the need to tackle this undertaking in a systematic way that presupposes important structural changes of systems of education. Nutbrown (1994), for instance, suggested the implementation of changes that will eventually lead to 'a curriculum for thinking children' (p. 117). Similarly, Fisher (1998) refers to 'a thinking curriculum' that will place the development of thinking at the heart of the educational process, and Perkins argues that 'To teach for thinking, it is not enough to teach skills and strategies. We need to create a culture that 'enculturates' students into good thinking practices' (1993: 98).

The strong and plausible arguments in favour of the teaching of general thinking skills and the promising claims put forward by its advocates resulted in the launch of a plethora of projects in this direction. Feuerstein's 'Instrumental Enrichment', 'The Somerset Thinking Skills Course', Lipman's 'Philosophy for Children', 'Cognitive Acceleration through Science Education' (CASE), 'Thinking through Geography' and 'Activating Children's Thinking Skills' are only a few examples of such projects (see McGuiness 1999). Against this backdrop, Fisher (1998) speaks of a world-wide 'philosophy for children' movement, which attempts to enhance the thinking, learning and language skills of students of all ages and abilities, by means of philosophical enquiry.

General thinking skills and metacognition

Following Vygotsky as one of the first to realize that conscious reflective control and deliberate mastery were essential factors in school learning, Fisher makes the connection between general thinking skills and metacognition:

> If we can bring the process of thinking and learning to a conscious level, and help students to become more reflective, then we can help them to gain control or mastery over the organization of their learning. On this view effective learning is not just the manipulation of information so that it is integrated into an existing knowledge base, but also involves directing one's attention to what has been assimilated, understanding the relationship between the new information and what is already known, understanding the

> processes which facilitated this, and being aware when something new has actually been learned. It involves not only thinking, but a metacognitive process: thinking about thinking. (1998: 14)

Typical of the connection between the study of thinking skills and metacognition is the fact that, in a review of research into thinking skills, commissioned by the Department for Education and Employment in the UK, one of the key conclusions was that a metacognitive perspective should be part of the general theoretical framework of similar research (McGuinness 1999). A strong link between the two areas is evident, based on the assumption that metacognition is a mental skill that entails a great deal of thinking. Metacognitive skills are thinking skills requiring appropriate stimuli for their 'awakening' and gradual development. Metacognition is not something to be 'taught' to the learner in an 'outside–in' process, but rather it is a skill that can be helped to develop in an 'inside–out' manner (Georghiades 2001a).

There is currently growing literature advocating the introduction of children to philosophical and reflective thinking early in their lives (Costello 2000, Fisher 1995, Lipman 1985), suggesting that the practice of advanced thinking skills is feasible with young children (Nutbrown 1994). This is at the core of the discussion undertaken in the next section, which addresses the question whether it is possible for metacognition to be practised by young children.

Metacognition and young children: implications from the teaching of general thinking skills

One aspect of the literature on metacognition currently characterized by some clash of opinion relates to the question whether primary aged children can or cannot benefit from, or are even able to experience, metacognitive activity. Brown (1987), for instance, has discussed that, for Piaget, reflected abstraction requires hypothesis testing and evaluation, and the ability to imagine possible worlds and their outcomes. Reflection, therefore, demands formal operational thought (Piaget 1976) and for this it is rarely attributed to the very young child or novice, no matter how precocious they might be (Brown and DeLoache 1978). Casting further doubt as to the 'appropriateness' of practising metacognition with children of young ages, Adey et al. (1989a) offered evidence of 11-year-old boys not benefiting from a series of intervention lessons that incorporated metacognitive elements, positive outcomes being restricted to girls of the same age, or to older age groups.

Others, on the contrary, have been advocating the engagement of young learners in metacognitive thinking. Gunstone (1994), for instance, asserts that '. . . all students have metacognitive ideas and beliefs of some form' (p. 134); hence the use of the term 'enhancing metacognition' in his writings. Scholars who favour the practice of metacognition early in the learners' school lives base their claims on evidence obtained from research with primary aged children. One such example is Matthew Lipman's 'Philosophy for Children', which was implemented with 5-year-old to 16-year-old children and has been successful in promoting metacognition (Lipman 1982, 1985). Georghiades (2002, 2004), who employed metacognition alongside normal science teaching with 11 year olds, presented material such as concept maps (Georghiades and Parla-Petrou 2001) and annotated drawings produced by the pupils during metacognitive activities, which entailed signs of reflective thinking on their understanding and the processes of their learning.

Similarly, Rudd (1992) recorded increased learning awareness even in cases of 8 and 9 year olds who produced complex and revealing concept maps about their learning. Interestingly, Adey et al. (2002) have recently redirected their efforts towards younger ages. They extended their work to include Year 1 primary school pupils in studying the effect of their cognitive intervention programme on the cognitive development of the children, metacognition being one of the main pillars of their scheme of work. In their results they reported significantly greater gains in cognitive development for the experimental group.

Although in the past Adey and Shayer (1994) appeared to be among those who were sceptical about the potentials of metacognitive instruction to primary school children, even at that stage their discussion managed to offer the other camp a strong argument in favour of an early involvement with metacognition. They specifically reported that, in ordinary mixed-ability high schools, the most able 12 year olds were operating at the level of average 18 year olds, or higher, and the least able at the level of average 6 year olds. This age range clearly suggests that at least some of the children in primary school are able to cope with metacognitive instruction, since they can reportedly operate at the level of 18 year olds. It also indicates that even when dealing with more mature ages (i.e. secondary students) there will be students operating at levels resembling the ones of their primary peers, hence setting the appointing of 'metacognitively appropriate' ages at question.

The problem with young ages did not escape Flavell's (1987) attention, as he related this to the important role metacognitive experiences play in everyday cognitive lives. As one grows older, Flavell said, one learns how to interpret and respond to these experiences. The converse implication is that young children may have such conscious experiences, but may not know how to interpret them very well. In other words, children simply may not know what these experiences mean and imply. In response to Piaget's stage theory, Flavell (1985) questioned the feasibility of identifying clear-cut stage-like 'cognitive metamorphoses' during childhood and adolescence, and conversely suggested the existence of 'developmental trends' during these years. He identified 'the developing sense of the self as an active cognitive agent and as the causal centre of one's own cognitive activity and the increase in planfulness' (Flavell 1987: 26) as two changes in the development of children that could possibly contribute to the acquisition of metacognition. Following Flavell's reasoning, and in view of ample evidence from the 'thinking skills camp' that favours the involvement of young children in reflective thinking (Haywood 1997, Lipman 1982, 1985), the question at issue is not whether children have the potential to engage in metacognitive activities; rather it is one of finding the right ways and the right activities for initiating and enhancing such activity. The scope, therefore, should be one of helping children to interpret metacognitive experiences, getting them to know what they mean and imply. The section that follows serves in getting to know the monster better.

Features of the nature of metacognition

Cognition versus metacognition

Albeit fashionable as a research area and a promising teaching strategy in its own right, metacognition has proved to be a complex and often poorly understood notion (Brown 1987). Typical of the problematic and undefined nature of metacognition is the fact that Flavell's contribution to Weinert and Kluwe's (1987) book *Metacognition, Motivation, and Understanding* was titled 'Speculations about the nature and development of metacognition'. Any attempt to discuss the nature of metacognition is inevitably linked to the problem of distinguishing what is 'meta' and what is 'cognitive' (Brown 1987). Weinert (1987), for instance, admitted that:

> On the surface, it seems easy to distinguish between cognition and metacognition. Metacognitions are second-order cognitions: thoughts about thoughts, knowledge about knowledge, or reflections about actions. However, problems arise when one attempts to apply this general definition to specific instances. These problems concern whether metacognitive knowledge must be utilized, whether it must be conscious and verbalizable, and whether it must be generalized across situations. (p. 8)

In an attempt to make such a distinction clear, Flavell (1976) suggested that cognitive strategies 'facilitate' learning and task completion, whereas metacognitive strategies 'monitor' the process. To use a clear-cut example by Flavell (1976), asking oneself questions about this article might function either to improve one's knowledge (a cognitive function) or to monitor it (a metacognitive function), hence demonstrating co-existence and interchangeability of cognitive and metacognitive functions. For Forrest-Pressley and Waller (1984), cognition is referring to the actual processes and strategies used by the learner, whereas metacognition is referring to what a person knows about his/her cognitions and to the ability to control these cognitions. Watts (1998), on the contrary, views metacognition in a hierarchical relationship to cognition. It is a metalanguage, he says, which permits individuals to talk about what is happening in their first level of feedback-governed learning, representing second-order change.

An essential characteristic of metacognition as 'metalanguage' is that such 'talking about' should entail more than the simple description of previous thoughts or actions. Metacognitive reflection involves the critical revisiting of the learning process in the sense of noting important points of the procedures followed, acknowledging mistakes made on the way, identifying relationships and tracing connections between initial understanding and learning outcome. This is a key characteristic to be included on the list of features distinguishing between cognitive and metacognitive activity, for, although it is possible for cognitive activity (and consequently learning) to take place without a critical approach on behalf of the learner, the practice of non-critical metacognition is not possible. It is common experience, for instance, that learners often engage in the learning process in passive ways, reproducing information without scrutinizing it and following instructions or applying formulae without knowing what the purpose of their efforts is. No matter how unsophisticated or superficial such learning behaviour is, these learners successfully activate and engage in cognitive functions, in order to carry out their tasks, even in the absence of any critical thinking. What this is suggesting is that passive, non-critical learning, although limited, is possible. Metacognitive monitoring of the process of learning or task completion, on the contrary, entails more than passive observing. It requires an element of judgement that is essential in comparing, assessing and evaluating the content or the processes of one's learning (self-appraisal). This judgement-laden reflective feedback will later enable the metacognitive learner to take informed action for rectifying the situation (self-management). Clearly such behaviour demonstrates that being critical is *sine qua non* for metacognition. Notably, engaging in critical self-appraisal is an endeavour that requires strong affective support for the learners, who should feel comfortable with the idea of identifying, acknowledging and reporting their errors, partial understandings, or personal routes towards learning. Attention should therefore be given to establishing supportive class environments that will encourage learners to demonstrate such learning behaviour, in essence taking responsibility of their learning.

Metacognition: a 'blanket' term?

A widely discussed feature of metacognition is the 'blanket' use of the term (Brown 1987) suggesting that the term embraces more than it can unproblematically represent. Returning to the definition by Flavell (1979), metacognition is knowledge that takes as its object or regulates any aspect of any cognitive endeavour. This view of metacognition denotes a fundamental duality in nature, suggesting that the metacognitive learner is capable of both stating knowledge about cognition and regulating such knowledge. The fact that a single term was used to refer to both knowledge about cognition and regulation of cognition is believed to have been the cause for confusion in the literature.

Discussing the first dimension of 'knowledge about cognition', Brown (1987) suggested that it is relatively stable, often statable and can be fallible. She acknowledged that this type of knowledge is assumed to be late developing and that it requires learners 'stepping back' and considering their own cognitive processes as objects of thought and reflection. 'Regulation of cognitions', on the contrary, said Brown (1987), comprises activities that are relatively unstable and age independent. She also pointed out that they are often not statable, arguing that knowing how to do something does not necessarily mean that the individual is consciously aware of the activities involved nor that these can be reported on to others.

Following a similar analytical approach Nelson and Narens (1990, 1996) proposed a theoretical mechanism to represent a metacognitive system consisting of two structures, an 'object-level' and a 'meta-level', the latter containing a model of the former. The mechanism incorporates two relations in terms of flow of information from one level to the other comprising 'control' and 'monitoring' functions. 'Control', which is the information flowing from the meta-level to the object-level, affects the object-level processes by initiating, continuing or terminating an action. 'Monitoring', on the contrary, lies on the assumption that the meta-level is informed by the object-level, a process that results in changing the state of the meta-level's model.

In an attempt to clarify some of the obscurity covering what metacognition stands for, Flavell (1987) proposed a taxonomic categorization of the components of metacognition. In doing so he distinguished between (a) 'metacognitive knowledge' and (b) 'metacognitive experience'. 'Metacognitive knowledge' is that part of one's knowledge that refers to cognitive matters. It comprises knowledge of person variables (knowledge concerning what human beings are like as cognitive organisms), task variables (referring to knowledge about how the specific information encountered affects and constraints the way in which one deals with it) and strategy variables (knowledge about cognitive strategies or procedures for achieving various goals). 'Metacognitive experience', on the contrary, comprises conscious experiences that can be either cognitive or affective and are pertinent to an ongoing cognitive situation or endeavour. To use another of Flavell's (1987) examples, if one has the anxious feeling that he/she is not understanding something and wants and needs to understand it, that feeling would be a metacognitive experience.

Hertzog and Dixon (1996) referred to multiple types of metacognitions classifying these as 'stored' or 'concurrent'. 'Stored metacognitions' comprise representations or information held in permanent, long-term memory either in the form of knowledge or beliefs. 'Concurrent metacognitions', on the contrary, are the information generated by, and associated with the act of cognising. As such, Hertzog and Dixon (1996) say they are directly related to the control processes responsible for monitoring the current status of the cognitive system (Nelson and Narens 1990), and they may be associated with conscious awareness of the content and processes of cognising (Cavanaugh 1989).

Instead of referring to a taxonomy of metacognition, Von Wright (1992) distinguished two 'levels of reflection'. At the lower level the learner is:

> capable of reflecting about many features of the world in the sense of considering and comparing them in her mind, and of reflecting upon her means of coping in familiar contexts. However . . . she is unlikely to be capable of reflecting about herself as the intentional subject of her own actions. (Von Wright 1992: 60–61).

At the higher level, however, he says that:

> Reflecting about one's own knowledge or intentions involves an element which is absent from reflections about the surrounding world. Self-reflection presupposes, in the language of mental models, a 'metamodel': in order to reason about how I reason, I need access to a model of my reasoning performance. (Von Wright 1992: 61)

Von Wright acknowledges that the distinction between these two levels of reflection was previously made by cognitive psychologists, such as Lev Vygotsky, who drew the line between 'soznanie' or consciousness, and 'osoznanie' or conscious awareness. The confounding of the two levels of reflection distinguished by Von Wright is thought by some scholars (for example, Adey and Shayer 1994) to be one of the reasons for the confusion in the literature. This is an important point to make, for the notion of consciousness is tightly associated to metacognition, the latter being roughly seen as invoking the former. Even if such a relationship applies, there remains the question 'what does the learner become conscious of, as a result of metacognitive reflection?'. In a case of 'tip-of-the-tongue' phenomenon, for instance, the learner may be conscious of the fact that he/she knows who the inventor of the telephone was, but cannot recall the name of Graham Bell. In this case, the metacognitive learner is conscious of possessing the specific piece of information (and of his/her inability to retrieve it at that moment!) yet he/she is not conscious of the information itself; that is, the name in question. It seems therefore that voices in the literature warning that metacognition need not necessarily give rise to awareness and that the two should not be treated unproblematically (Kentridge and Heywood 2000, Rosenthal 2000) are fully justified. The relationship between metacognition and consciousness can be a complex one.

These examples of attempts to analyse or classify the concept of metacognition are, of course, not the only ones available in the literature, yet they manage to present sufficiently the prevailing approach to talking about metacognition. Important as such analyses might be, an underlying unifying idea should oversee any classification scheme, acknowledging that 'Metacognitive knowledge, awareness and control are all learning outcomes as well as fundamental influences on the extent of achievement of more usual learning goals' (Gunstone 1994: 134). The fact remains, however, that identifying or measuring metacognitive activity is a task that can prove highly problematic, as the discussion that follows will show.

Identifying and measuring metacognition

Close to the problem of sufficiently defining metacognition lies the difficulty of identifying and assessing students' metacognitive abilities or performance. This is a practical obstacle caused by the fact that metacognition is an inner awareness or process rather than an overt behaviour (White 1986), and because individuals themselves are often not aware of these processes (Rowe 1991). In employing interviews for educational purposes, for instance, there is difficulty in judging whether a pupil who takes some time before replying to a question is unsure and unconfident about his/her response, or whether that silent interval is a sign of one's effort to reflect back on his/her learning and retrieve the answer in a metacognitive manner. Adey and Shayer (1993) traced the problem of illustrating metacognitive elements of an intervention programme to the fact that this is more a feature of the teacher's strategy than of the printed materials. Similar problems with the study of reflective thinking seemed to be evident in the early years of employing 'introspection' by some psychologists for, according to William James, attempting to grasp the mind through introspection is like 'turning up the gas quickly enough to see how the darkness looks'! Attempts towards identifying metacognitive thinking can be based on the acknowledgement that metacognition as understanding of knowledge can be reflected in either effective use or overt description of the knowledge in question (Brown 1987). In other words, it is possible for metacognition to be detected if the learner is able to effectively use or overtly describe such understanding. Reasonable as this approach to identifying metacognition might seem, it fails to provide an answer to the question of how to measure metacognition reliably.

In order to measure 'knowing about knowing' 'more accurately' it has been suggested (Ericsson and Simon 1980, Garner and Alexander 1989) that researchers should use multiple methods that do not share the same source of error. Garner and Alexander (1989) proposed three ways of finding out what children know about their cognitions: (a) asking them, (b) having them think aloud while performing a task, and (c) asking them to teach a younger child a good solution for a problem. In making these suggestions Garner and Alexander (1989) did not fail to acknowledge a number of problems, including children's lack of verbal fluency or variation in adult–child use of language; young children's difficulty in discussing general cognitive events; and their tendency for describing specific just-experienced events. Flavell (1987) predicted that 'in the future' methods for measuring and assessing metacognitive experience would develop. Fifteen years later the existence and trustworthiness of such methods are highly questionable. The lack of consensus in the literature regarding how to recognize and measure metacognition in action, along with the absence of reliable tools for this purpose, means that any attempts are bound to be problematic and heavily dependent upon the subjective judgement of researchers.

In conclusion, Nelson's (1998) views successfully reflect the current state of metacognitive literature, particularly in relation to attempts to address the nature of metacognition:

> While it would be incorrect to think that the theories of metacognition are currently so highly developed that the applications to education are straightforward, it would also be incorrect to assume that our current ideas about metacognition are so fragmented and poorly developed that any application to education would be premature. (Nelson 1998: xi)

The acknowledgement that, albeit partial, our understanding of metacognition has matured enough to be applicable to educational contexts has been the driving force behind a significant body of research with an interest in metacognition. The fact that important research outcomes initially emerged in areas other than that of science education, along with the fact that metacognitive research in relation to science education has not yet produced sufficient amounts of work, imposes the necessity for looking at both directions. Studies in metacognition within science education are hence examined next, alongside studies with a similar interest accommodated in other areas. In doing so aspects of the underpinning philosophy, the objectives and the methodology of these studies are selectively discussed.

Studies in the outcomes of metacognition

Since the emergence of metacognition as a new notion considerable research has been carried out, with metacognitive dimensions holding either a central or a secondary position. Most of these projects shared the same anticipation, one of improving learning outcomes as a result of the practice of metacognition (Hacker et al. 1998). Over the years, metacognition has been related to a number of general cognitive abilities and aptitudes such as intelligence (Borkowski 1985), general aptitude (Swanson 1990), and memory (Pressley et al. 1985), or more subject-specific areas such as mathematics (Schoenfeld 1987) and reading (Cross and Paris 1988). Of these areas, the one with the most explicit connection to metacognition was the broad area of thinking skills that was discussed earlier, based on the belief that for higher level thinking to be generalized students should be given opportunities to think about their own thinking. Most of these studies offered ample evidence of a positive impact of metacognitive activity on student thinking and learning (for example, Nickerson et al. 1985, Perkins and Salomon 1989), a conclusion that, as will be discussed later, was supported by research reports from within science education.

Research in metacognition has covered mainly three components: (a) 'knowledge about strategies', which refers to knowledge about when, where and why different strategies should be used; (b) 'strategy use', referring to the children's actual use of metacognitive strategies without instruction or prompts; and (c) 'cognitive monitoring', which is a metacognitive acquisition procedure needed for evaluating and changing strategy use and for determining the limits of the knowledge (Chmiliar 1997). Among the conclusions reached by metacognitive research to date are that: (a) knowing about knowing develops, (b) both children and adults often fail to monitor cognitions, and (c) some strategies are difficult to learn and easy to abandon (Garner and Alexander 1989).

The fact that the link between metacognition and thinking skills encouraged application of the former to improve the latter has resulted in a number of researchers focusing on groups with learning difficulties. Feuerstein et al. (1980), for instance, worked with disadvantaged underachieving children in employing their Instrumental Enrichment, while Campione (1987) studied metacognition mainly in relation to students with learning problems and sometimes with mentally retarded children. Others, on the contrary, focused on the importance of establishing the independence of metacognition from general aptitude. In one such study, Swanson (1990) investigated whether high levels of metacognitive knowledge about problem-solving could compensate for overall aptitude. He found that highly metacognitive students outperformed less metacognitive students in problem-solving regardless of their overall aptitude level. In fact, he reported that high-metacognitive/low aptitude children performed significantly better than low-metacognitive children with higher overall aptitude scores. He hence concluded that high performance on the problem-solving tasks is more closely related to children's performance on the metacognitive measures than on the overall aptitude measures. This was a position that was previously supported by other studies in the literature (for example, Minsky and Papert 1984, Slife et al. 1985). Interest in metacognition over the past three decades has reportedly resulted in positive shifts in students' learning outcomes, hence justifying the view that 'effective learners operate best when they have insights into their own strengths and weaknesses and access to their own repertoires of learning' (Brown 1994: 9). Interestingly, most of the work on metacognition was conducted in relation to students' perceptions and beliefs regarding learning and the learning processes (for example, Thomas et al. 1997). Focusing on the impact of metacognitive thinking on taught subject matter and on learners' understanding was clearly overlooked.

Having broadly sketched the scenery of general metacognitive research, attention is now drawn to three projects that were either partly or exclusively conducted in the field of science education. These projects are the Project to Enhance Effective Learning (PEEL) in Australia and CASE in the UK, followed by reference to research by Georghiades (2001a) in Cyprus.

Project to Enhance Effective Learning

PEEL, which was a multiple-year cross-subject approach aimed at secondary school students' understanding and informed responsibility for their own learning (Baird and Mitchell 1986, Gunstone 1991), was one of the large-scale projects that included an extensive metacognitive dimension. Contrary to other studies in the field of science education (for example, Adey et al. 1989a,b) the approach followed by PEEL did not include 'special' classes at 'special time', but was meant to pervade all the lessons students had. The project was not identified with one or two teachers only, but it engaged six faculties (English, History, Geography, Integrated Studies, Commerce and Science), therefore exposing targeted classes to as many PEEL teachers as possible. The project did not apply a set of pre-specified activities, instead the teachers were free to introduce any activities they felt that were serving the objectives of PEEL.

Typical of the work done within the project was the work by Baird (1986a, b) who investigated ways of improving the metalearning of students in the science classroom. He introduced a number of materials and procedures, such as a checklist of questions to be considered by the students in each lesson (e.g. 'What is the topic?', 'What do I know about it?', 'Why am I doing it?'), students' diaries for answering these questions and for evaluating their learning each lesson, frequent discussions of the purpose of learning, and interviews with teacher and students. Although Baird found that students had become more purposeful learners with greater understanding of content, he also concluded that any true progress was difficult if metalearning was limited to a single subject for a number of periods per week with one teacher only.

In evaluating the outcomes of PEEL, Gunstone (1991) identified four emerging issues of considerable importance: (a) student views about learning, teaching and their role in the teaching process formed a substantial barrier to improved metacognition; (b) affective issues were a significant part of student reactions to and valuing of PEEL; (c) making PEEL fruitful to students was an ongoing problem; and (d) teaching approaches that are constructivist and metacognitively oriented depend on learners having trust in their teachers. In general, the outcomes of the project have been encouraging: metalearning can be promoted and will facilitate conceptual change even if it remains fragile and artificial until perceived by students as meeting their own short-term goals (White and Gunstone 1989).

Cognitive Acceleration through Science Education

Equally significant research was presented by the CASE project in the UK. Its main aim was to explore an approach that hopes to improve pupils' ability to learn under the widespread effort of 'raising standards'; that is, of improving long-term achievement. Metacognition was one of the main pillars of the intervention programme employed (Adey and Shayer 1994).

The project developed a set of materials comprising a teachers' guide and pupils' worksheets for 30 lessons titled 'Thinking Science' (Adey et al. 1989b). The researchers used experimental 'CASE classes' and control classes working with Year 1 (aged 11 +) and Year 2 (aged 12 +) students in mixed comprehensive secondary schools. Instead of their normal science lesson, CASE classes were given a 'Thinking Science' activity once every 2 weeks, while control classes continued with their normal science lessons. This arrangement lasted for a 2-year period.

The CASE project provided very promising results in the form of long-term and general effect. Long-term because students who participated in the CASE groups presented better achievement 2–3 years after the intervention had ended, and general because better achievement was reported in widely different subjects (i.e. science, mathematics and English) (Adey et al. 1989a). Although in the early years of CASE positive effect was restricted to girls or to groups starting at age 12 + , more recent results have shown that the intervention works with children as young as 5 year olds (Adey et al. 2002). CASE has grown dramatically since its launch and is currently applied in tens of schools and Educational Authorities in the UK.

Research by Georghiades: situated metacognition

Georghiades (2000, 2001a) studied the effect of metacognition on prolonging the durability of children's conceptions of school science and on enhancing their ability for contextual use of these conceptions. In so doing, no attempt was made to teach metacognition as a thinking skill per se; rather metacognitive instruction was blended with the subject taught, anticipating a positive effect on children's understanding of related science. This approach to the practice of metacognition is called 'situated metacognition' (Georghiades 2004) and marks an attempt to bring together metacognitive thinking and science subject matter, in the belief that the former enhances understanding of the latter.

The research was conducted in Cyprus with Year 5 pupils studying 'Current electricity', following a quasi-experimental design with one experimental and one control group. Both groups were taught the unit over a 4-week period, the only difference in their treatment being the employment of metacognition in the teaching of the experimental group. This was done by means of the 'metacognitive instances' approach (Georghiades 2001b, 2002, 2004), according to which the teacher implants brief metacognitive activities such as classroom discussions, annotated drawing, concept mapping and keeping diary-like notes at selected points of the teaching sequence. Pupils' performance in the concepts taught was tested by means of written tests and interviews on three occasions spread over one school year.

Classroom discussion and the material produced by the children in the course of the research have shown that 11 year olds can engage in metacognition, provided this is accommodated in suitable activities, therefore offering further support in favour of an early engagement of children in reflective thinking. It was also demonstrated that metacognition is more effective when practised in small groups of children rather than as whole-class instruction. With regards to the effect of metacognitive thinking on children's science learning, both qualitative and quantitative measures provided evidence that metacognitive instruction can have a positive impact on the durability of pupils' conceptions of science and on their ability to use their knowledge in exercises with significantly different contextual requirements. The former outcome is one that verifies the findings of Blank (2000) who offered teachers and students formal opportunities to talk about their science ideas, and reported that students who practised metacognition experienced more permanent restructuring of their understandings of ecology.

In summary, the growing metacognitive literature in science education is beginning to verify and strengthen the claim that metacognition can indeed have a positive role to play in science teaching and learning (for example, Davidowitz and Rollnick 2001, Davis 1996, Henriksen et al. 1996, Thomas and McRobbie 2001). Working towards 'metacognitively enhanced science learning' could therefore be a promising future direction for science education.

Science education and metacognition: future directions

Our understanding of the mechanisms and the nature of metacognition to date remains incomplete and controversial, living up to its description as 'a many-headed monster' (Brown 1987). Central to the problems relating to metacognition is finding ways of recording and making available to others one's metacognitive thoughts. Both identifying and 'measuring' metacognition currently rely heavily on researchers' subjective interpretation in assessing what is cognitive and what is metacognitive. Attempts in this direction are usually restricted to the observable elements of one's metacognitive thinking; that is, what one says and what one does. What remains unsaid by the researched could entail a richness of reflection that remains unexplored by researchers. More research is needed that will enhance our understanding on what constitutes metacognition, how it can be identified, and whether it can be taught and how. These are just a few of the questions that are important to metacognitive literature, irrespective of discipline.

In the case of science education, research in metacognition is practically at its infancy. The existence of unanswered questions such as those just listed is contributing towards the relatively limited volume of work currently available in science. Research available to date seems fragmented and in lack of coherence, for it is scattered in the three areas of physics, chemistry and biology, and across an age range that usually extends to university students or science teachers, often overlooking primary school ages. The discussion in this paper on metacognition in relation to young learners was largely intended to trigger greater interest among science educators in metacognition and primary science. The diversity and heterogeneity of metacognitive studies in science also make the verification of reported findings and generalization of conclusions difficult, in essence restricting trust among science educators in the potentials of metacognition. Future research attempts should concentrate on explicitly and systematically studying the educational impact of reflective thinking on children's science learning, ideally starting from an early age. Examining the role of metacognition in addressing and attempting to change children's alternative explanatory frameworks, developing scientific investigating skills or enhancing transfer of scientific understanding are only a few exciting directions of enquiry that could benefit contemporary science education. The outcomes of such research will consequently justify or reject the inclusion of metacognitive thinking as a component of science curricula.

The notion of metacognition is largely unknown to the average science teacher. Those of them who happen to be familiar with the notion do not have the resources to facilitate implementation of metacognition in their teaching, or they do not have the authority to make such changes on curriculum and time allocation as to accommodate metacognition in their teaching. The current state of the literature on metacognition has already given signs of a theory–practice gap emerging, comprising extensive academic elaboration on the mechanisms of metacognitive thinking and rare attempts to bring this inside ordinary classrooms. If metacognition is to find its way into the science classroom this decision has to be made by policy-making bodies, which will consequently facilitate ordinary teachers in their attempts to do so. The conduct of research on the use and training of metacognition in 'natural contexts' (Davidson et al. 1998) is one way of taking a step forward. Until such changes are brought about, the practice of metacognitive thinking in science education will rely heavily on the initiative of small groups of teachers, who will have to invent both the resources and the time for such engagement.

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