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Defining Metacognition: A step towards recognising metacognition as a worthwhile part of the curriculum.

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Abstract

Researchers, educators and curriculum documents promote the importance of metacognition for student learning but much confusion in the field continues to exist about what the term 'metacognition' means. This lack of clarity creates obstacles for researchers and educators. It is difficult to assess what cannot be defined. Because of the importance attached to assessed curriculum, a likely implication is that metacognition will not be widely embraced as a worthwhile part of the curriculum unless metacognition is clearly defined and is included as part of assessment practices.

This paper reports on a study which investigated the notion of metacognition and its assessability within the curriculum domain of mathematics. Techniques frequently used for monitoring metacognition are criticised in terms of validity and reliability. The study was planned to minimise limitations of individual techniques and attend to questions of legitimacy. Thus, a new, multi-method approach was developed and trialled for the assessment of metacognitive functions (Awareness, Evaluation and Regulation). The main features of this approach were a hands-on card sorting task and video

stimulated recall used within the context of a problem based clinical interview. This paper does not focus on the technique used.

The study involved 90 interviews of year six students from three different schools. The study provides details about the theoretical nature of metacognition, empirical results about metacognitive behavior during mathematical problem solving and presents a tested model of metacognition. The results show that the sequence of student metacognitive behavior is predictable regardless of school, class, sex and task.

Introduction

The importance of metacognition for student learning has been widely acknowledged (Anderson and Walker, 1991, Baird, 1998, Biggs, 1987, Birenbaum, 1996, Brown and De Loache, 1983, Campione, 1987, Gourgey, 1998, Pintrich, and De Groot, 1990, Schraw and Moshman, 1995, Schoenfeld, 1987, Wilson and Wing Jan, 1993, Wilson and Wing Jan, 1998). In discussing the role of metacognition in teaching and learning, Hartman (1998) described metacognition as especially important because it affects so many elements, such as acquisition, comprehension, retention and application of what is learned.

Although interest in research in the area of metacognition and related fields began early in the century (Dewey, 1933), pioneering research on metacognition (mostly in developmental psychology) occurred in the late 1960s and early 1970s. Flavell's work in the early 1970s instigated much discussion about the meaning of metacognition and sought to explain general development patterns of children's knowledge about their memory processes descriptively.

Pertinent to this study is work investigating the connection between mathematics performance (particularly problem solving) and metacognition. This type of research has gained popularity since the 1980s (Adibnia and Putt, 1998, Lester, 1994, Silver and Marshall, 1990). A number of researchers have asserted the importance of metacognition for effective mathematical thinking and problem solving (for example, Clarke, Stephens and Waywood, 1992, Garofalo and Lester, 1985, Goos, 1995, Lester and Garofalo, 1982, Schoenfeld, 1985, 1987, 1992, Silver and Marshall, 1990).

But despite having necessary skills and concepts, students are not always able to successfully complete problems (Kilpatrick, 1985). A primary source of difficulties in problem solving has been suggested as a students' inability to actively monitor and regulate their cognitive processes (Garafalo and Lester, 1985, Lester and Garafalo, 1982b, Schoenfeld, 1987). Davidson, Deuser and Sternberg (1994) called for further research to clarify the role of metacognition in problem solving.

Although research related to metacognition is broad, a number of researchers have recently asserted that there is still much to be discovered about metacognition during problem solving (Davidson and Sternberg, 1998 and Dunlosky, 1998). According to Dunlosky (1998), knowledge of the interaction between metacognitive processes and different types of problems is one area which needs further exploration, if the role of metacognition within problem solving is to be enhanced. Schoenfeld (1985) called for a more detailed model of executive behavior during problem solving, one which deals with the issue rigorously and reliably. The problem of definition is basic to any such investigation.

Defining Metacognition

Even though research related to metacognition has grown in popularity over the last three decades, the term metacognition has often been used by researchers and educators in vague, confusing and sometimes contradictory ways (Brown, 1987, Weinert, 1987). After about a decade of discussion, even Flavell (1987) admitted that: 'none of us has yet come up with deeply insightful, detailed proposals about what metacognition is.' (1987 : 28).

Metacognition is often described as multi-dimensional and has been used as a general term about a range of disparate higher level cognitive skills (Thorpe and Satterly, 1990). What constitutes metacognition and what does not requires more clarity (Cavanaugh and Perlmutter, 1982, Kluwe, 1998, Nelson, 1998). Perkins, Simmons and Tishman (1990) suggested that the term 'metacognition' is hard to 'deal with'. They loosely defined the use of metacognition as: '...something you want to do more or less continuously, and the actions you need to take to maintain monitoring and to shift yourself back on task when you were off task.' (1990 : 286). A simple and unproblematic definition of what it is and a comprehensive strategy for teaching for metacognition remains unclear (Jacobs and Paris, 1987).

Varying definitions of metacognition exist in the literature but generally they include a number of components which are interrelated (Schraw and Dennison, 1994). Within the range of definitions, it is generally agreed that metacognition involves two components:

knowledge about cognition and regulation of cognition (Brown, 1987, Brown, Bransford, Ferrara & Campione, 1983, Garofalo & Lester, 1984, Schoenfeld, 1990, and Schraw & Dennison, 1994) but the nature of the relationship is not always clearly defined either. The postulated dual nature of metacognition provides only a superficial model of metacognition. It is not helpful in trying to explain how students use metacognition. Apart from the confusion related to the difficulty in defining and separating two aspects, problems in distinguishing between cognition and metacognition have also thwarted researchers (Brown et al, 1983).

In the area of mathematics, a number of important questions remain unanswered about what metacognitive and cognitive actions students actually make as they tackle problems. The findings from this study support the notion that the components of metacognition are related and interactive. Nevertheless each major component (referred to in this study as functions) requires specific clarification.

Indistinct boundaries and imprecision makes inquiry difficult (Brown et al, 1983). A more detailed model of metacognition is needed to answer questions about successful problem solving. More specific information about what primary school problem solvers do could assist practising teachers to improve the teaching and learning of metacognition and consequently enhance student problem solving. A clear definition of metacognition is required to provide the parameters for research and a means to analyse the results of the investigation.

Synthesis of the literature has led to the development of the following definition which will be used in this paper: Metacognition refers to the *awareness individuals have of their own thinking and their evaluation and regulation of their own thinking.*

The three metacognitive functions used within this study to describe student behavior, include: Awareness, Evaluation and Regulation. These functions of metacognition are defined as follows:

1. Metacognitive *Awareness* relates to an individual's awareness of where they are in the learning process, their knowledge about content knowledge, personal learning strategies, and what has been done and needs to be done.

2. Metacognitive *Evaluation* refers to judgements made regarding one's thinking capacities and limitations as these are employed in a particular situation or as self-attributes. For example, individuals could be making a judgement on the effectiveness of their thinking and/or strategy choice.

3. Metacognitive *Regulation* occurs when individuals modify their thinking. Metacognitive Regulation draws upon knowledge and uses 'executive' skills to make effective use of one's own cognitive resources.

This definition was used to develop a working model of metacognition which was used as a basis for designing the technique used in this study.

Method Overview

Although the method used in this study is unique and crucial to the trustworthiness of this study, it is not the focus of this study and therefore is only presented as an overview (for more details see Wilson, 1999).

Ninety interviews of year six students from three different schools were conducted. Each student was interviewed three times (including a familiarisation task). Students used a set of metacognitive and cognitive action cards (see Appendix) designed for this research to stimulate responses about their thinking during different types of mathematical problem solving (Spatial, Number and Logic tasks).

Aim and Subquestions of the Study

The major aim of this study was to *develop and apply a strategy for assessing metacognition* within the context of mathematical problem solving. Two subquestions included:

A. *What does the assessment strategy reveal about the nature of metacognition (as employed by Year six students)?*

B. *What is the relationship, if any, between metacognition and task type?*

The results related to the first subquestion are the focus of this paper.

A New Multi-Method Approach

The technique developed was given the term 'multi-method interview' (MMI). It included: a problem based clinical interview (incorporating self-reporting and a card sorting task), observation, audio recording and video stimulated recall. It responded to recommendations for new multi-method research methods to assess metacognition (Cavanaugh and Perlmutter 1982, Meichenbaum, Burland, Gruson and Cameron 1985, Mulcahy, Short and Andrews, 1991, Randhawa 1994).

A total of fourteen metacognitive action statements, each representing one of the metacognitive functions (Awareness, Evaluation or Regulation, see Appendix), were listed individually on playing cards. Cognitive and blank cards were also included in the set of cards.

Subjects were asked to attempt to solve a mathematics problem. When they stopped, they were asked to sort and sequence the action cards according to how they solved the problem. Cards which did not apply were discarded. Students problem solving attempts were video recorded, these were replayed after the cards had been placed in order. Students were then asked to check their card sequence as they watched the video to ensure that their card sequence was an accurate representation of their thinking. As a result of the video replay students could then change their card sequence if they wished. The resultant sequence of metacognitive actions was used to make hypotheses about the nature of individual metacognitive behavior and to evaluate the effectiveness of the technique. The use of the cards in the MMIs eliminated the "Do not know" responses given in the pilot questionnaire about metacognitive use.

Findings and Discussion

As a result of the empirical data collected, the expected sequence of behaviors has been summarised as three Grounded Metacognitive Principles. These are used as a basis for discussion about metacognitive behavior and lead to the models of metacognition presented.

Borkowski and Muthukrishna (1992) argued teachers do not have a working model of metacognition which guides their teaching, and further that a working model is a prerequisite to provide an instructional framework for strategy based teaching. The models of metacognition proposed are based on empirical data. They represent different aspects of the data. These models could be used for further research purposes or by classroom practitioners.

Student Metacognitive Actions During Problem Solving

Student sequences during problem solving demonstrated some differences but these were extremely rare. The application of simple inferential statistics to identify significant subgroups amongst informants suggested the group was characterised by similarity rather than differences.

First Grounded Metacognitive Principle:

During problem solving students commence at Awareness, then either Evaluate or Regulate their thinking. Their sequences finish with an Evaluative action. Cognitive actions will intersperse metacognitive sequences.

In this study, all possible transitions were reported by students (N=90), but most students reported beginning with the metacognitive function Awareness (N=68) and ending with Evaluation (N=87). Students reported evaluating much more regularly than anything else. The sequence Awareness to Evaluation to Regulation (A, E, R) was reported as often as Awareness to Regulation to Evaluation (A, R, E).

Awareness at the beginning of a sequence is a logical action, particularly when the problem is challenging. In problem solving situations, people need to call to mind what they know and have done at other times (A). They might then Evaluate (E) their thinking and then consciously construct a plan of action (R). This theoretically sound sequence of actions (A, E, R) was tested against the data and found to be true as often as the sequence: Awareness to Regulation to Evaluation (A, R, E) .

The transition from Awareness to Regulation is considered highly possible when the particular Regulation action statements are revisited. They included: 'I *made a plan to work it out', 'I thought about what I would do next' and 'I thought about a different way to solve the problem'* and *'I changed the way I was working'.*

Some students also reported Evaluation as their first metacognitive function but this seems implausible because students need to be evaluating something. However, in six of these cases Evaluation was preceded by a cognitive action. The plausibility of Evaluation as the first metacognitive act rests with the acceptance that cognitive action can initiate a problem solving attempt as reported. Similarly, a Regulation beginning seems likely only if cognition preceded that metacognitive function. This implies Awareness actions. It is possible that the process represented by Awareness was not recognised and therefore was not reported by some students.

Why is E the Last Action?

In nearly all cases students reported ending their sequences with Evaluation. They usually checked their answer and or the task requirements before they finished which seem like a logical conclusion. In 3/90 interviews students (from School 1), an Evaluation ending was not reported. This may have been due to the interviewer's inexperience. After School 1, if students reported a cognitive action as their last action, they were asked what they were thinking when they finished. All of these responses indicated the Evaluative function.

Model One: Metacognitive Function Use and Sequences

The basic model of metacognition (Figure 1) shows the metacognitive functions and allows for both the sequences of AER and ARE. The empirical data strongly suggests that Awareness is the first metacognitive function employed and Evaluation is the last. The most commonly reported entry and final point are indicated on the model by incoming and outgoing arrows.

Figure 1. Basic Model of Metacognitive Function Use and Sequences

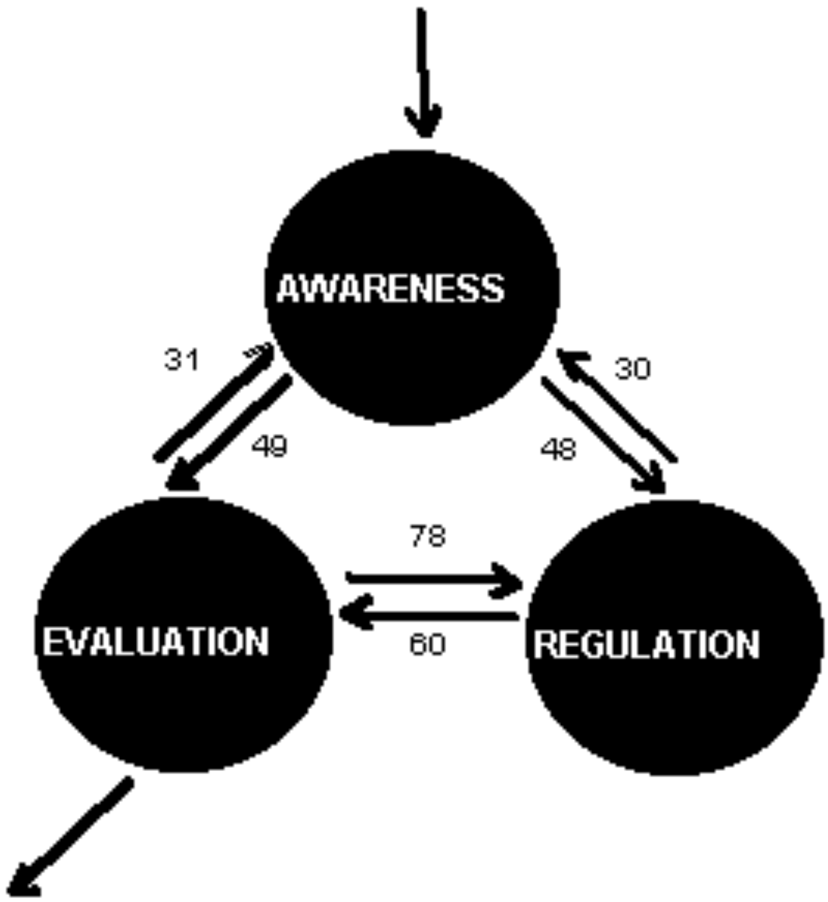


Figure 1 shows the possible and typical pathways between metacognitive functions. As can be seen from the model, all metacognitive transitions are employed to a significant extent. This model shows direct transitions between metacognitive functions, for example, Awareness to Evaluation. It does not show transitions between metacognition and cognition, for example, Awareness to Cognition to Evaluation). Because the model does not include cognition, a further model was designed (Figure 2).

The numerals on the model show uncanny symmetry of transition use. Figure 1 shows that the transitions from Awareness to Evaluation (N=49) are just as likely as Awareness to Regulation (N=48) and that Evaluation to Awareness (N=31) are just as likely as Regulation to Awareness (N=30). While not as similar as the above transitions, Evaluation to Regulation (N=78) is the most frequently reported transition but is not unlike the possibility of the transition Regulation to Evaluation (N=60).

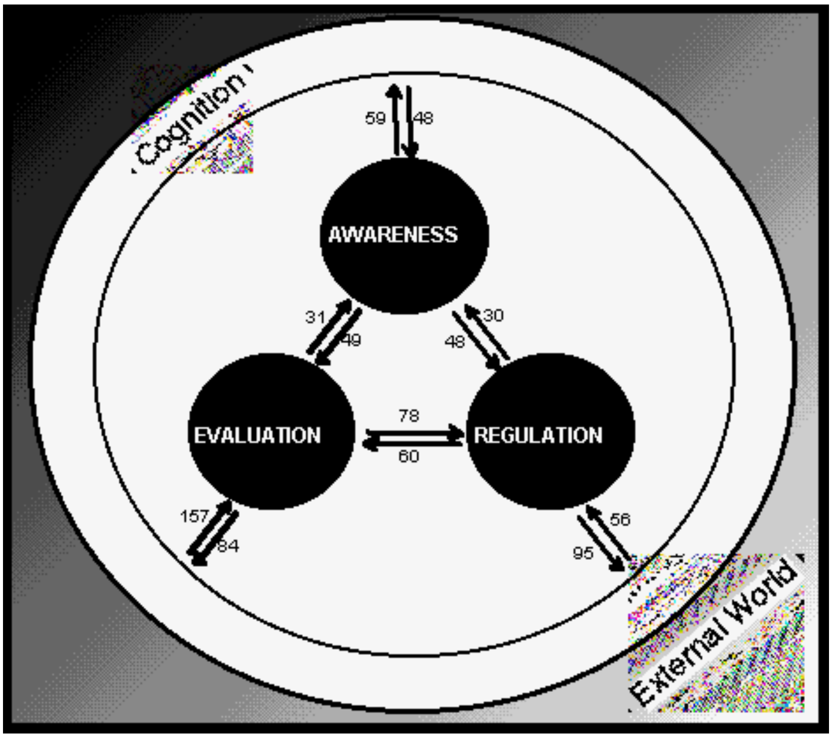
The relationship between cognition and metacognition is ill defined in the literature. Although not one of the initial intentions of this study to document this relationship, the importance of cognition in relation to metacognition in the problem solving process emerged during the data collection. Some generalisations about cognition have been made in this paper but further specific data collection would be beneficial.

Theoretically it could be expected that there would be frequent instances of Cognition to Evaluation (N=157), Regulation followed by Cognition (N=95) would also be expected. These were the most frequently reported transitions. Other transitions from and to Cognition, especially involving Awareness were less expected and less often reported because of the limited use of Awareness after its initial use to commence the problem solving process. The relationship between cognition and metacognition is taken up later in this paper.

The model below reflects the fact that Cognition was reported at any stage of all sequences. Metacognition is separate from but related to cognition, it has been presented as such in the model. The model is a schematic representation of the empirical findings of this study and in this form does not show features such as the most common starting and ending point or the repeated use of actions: A to A, E to E, R to R and C to C.

Figure 2 (below) is argued to be theoretically coherent and representative of the data. It is proposed as applicable when challenging problems are provided to upper primary children.

Figure 2. Elaborated Model of Metacognition and Cognition



It is noted that individuals can reflect upon their feelings, their emotional state, their attitudes, values, inclinations and beliefs. They may even evaluate and regulate these. This sort of activity is metacognitive in character, but the application of this reflection on an individual's affective functioning was not the subject of this research and consequently not within the parameters of the data collection. It is possible that an analogue of the model may apply in relation to student affect, but no such claim is made on the basis of this study.

The Validity of the Model

A number of questions should be asked of any model, these include: Is the model empirically consistent with the data, theoretically consistent and what does the model tell us about the research focus? The following statement responds to these important questions.

The model is asserted as largely consistent with the data and theoretically conherent. It shows that all the metacognitive processes must have cognition as an object. In this research setting, the problem solving task is part of the students' experience upon which their cognition acts. Metacognition, by its nature acts upon cognition and the products of cognition, rather than upon features of the student's external world/environment, such as the problem. Figure 2 acknowledges that metacognition never interacts with the problem directly. Interaction with the world occurs through cognition.

Students cannot go directly to metacognition without cognition, even though they may not recognise their initial cognition, they will have at least read or thought about the problem.

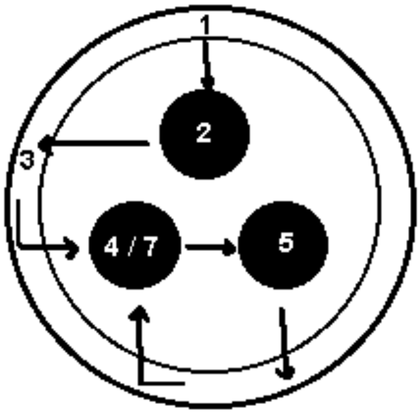
The Nature of Metacognition: Theoretically and Empirically

Theoretically it is reasonable to expect that Evaluation would always be preceded by an Awareness action and that every Regulatory action would be preceded by an Evaluative action. But data other than the expected sequence was reported, therefore Figure 2 (above) was designed to take into account the varying reported sequences. Ericsson and Simon (1980) suggested that omissions need to be considered when the reasonable expectations of researchers does not match the data:

> When subjects do not verbalise information that the investigator has strong reasons to assume they would need to have available to perform the task, it is reasonable to conclude that the protocols provide only an incomplete record of the process. (Ericsson and Simon, 1980 : 235).

It is acknowledged that omissions and incompleteness of data is possible. All sequences have been recorded as students reported them. The researcher could have inserted virtual c's (assumed cognitive actions) or metacognitive acts where these seem to be logical but the reported sequences were left unaltered. Two pathways (example sequences) have been diagrammatically represented below to demonstrate two possible actions. They are both feasible, logical and represented in the data. Figure 3 shows the problem solver commences with a Cognitive action, this is followed by Awareness, a Cognitive act, Evaluation of Cognition, Regulation, further Cognition and then the sequence is finished with an Evaluative action.

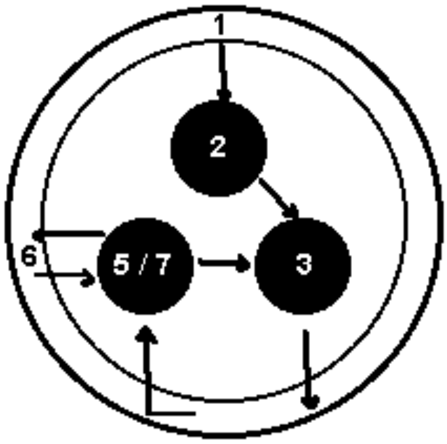
Figure 3. Example Pathway One



This pathway has a format face validity: it conforms to expectations of how problem solvers might intervene cognitive and metacognitive acts. There are documented instances of students who reported sequences like this one, therefore it is theoretically coherent and empiricially grounded.

Figure 4 shows the problem solver commences with a Cognitive action, this is followed by Awareness, Regulation, Cognition, Evaluation, Cognition and finished with an Evaluative action.

Figure 4. Example Pathway Two



Pathway Two resembles Pathway One except the relative location of the first Regulation and Evaluation acts in the sequence. If Regulation is associated with the need for a decision on the part of the problem solver as to how best to proceed, then Regulation based on Evaluation (Pathway One) seems plausible, as does Regulation on the basis of retrieval procedures (Pathway Two). Again, Pathway Two seems theoretically coherent and is empirically grounded.

Uncommon Sequences

This section discusses the less frequently reported sequences and possible reasons for divergence from the norm. Awareness was not always reported as the starting point. It could be that students reports were accurate and that Awareness is not always used at the beginning of the sequence. But there could also be a number of other reasons why Awareness is not recognised or reported at the beginning of a sequence. These are now considered. Sternberg (1998) suggested that metacognitive activity is not always called for and may at times hamper functioning. The nature of the tasks and their level of challenge may account for some anomalous beginnings.

Metacognition is likely to 'kick in' when a problem is non-routine. There may be little need to access metacognition for some type of tasks. For example, a simple recall type question like: five times five, may be responded to automatically. In this case no strategy selection may be required. Students may not be able to recall metacognition when processes have become automised (Ericsson and Simon, 1980, Mc Koon, 1992).

Another possibility is that students may be very familiar with particular sorts of task so they start immediately without conscious thought about thinking processes, they are 'bypassing conscious metacognitive activity.' (Sternberg, 1998 : 129) and therefore do not identify their use of Awareness.

Evaluation Beginnings

Where the first metacognitive action reported is an Evaluative statement, the researcher must consider a number of questions: What is being evaluated? In some instances this may be a cognitive action and therefore understandable. Another question which comes to mind is: Do students know explicitly what they can or cannot do? If not, some form of metacognitive Awareness would be required.

An example from the data is useful. Tim reported his first action card as: *'I thought about whether what I was doing was working'* (Evaluation). Tim must have done something to evaluate but he either didn't recognise this as important or didn't recognise it at all. Only one other student reported starting at Evaluation before any cognitive actions. This statements was: *'I thought I can't do it'.* In order to make such a judgement it seems likely that students would have considered what they already know and assessed their cognitive capacities as inadequate.

Regulation Beginnings

Where the first function reported was Regulation, the subsequent question is: What is being Regulated? Again this may be a cognitive act but the need for Regulation seems more likely if at least some form of Evaluation has taken place. Two students reported starting at Regulation before any cognitive actions. This seems feasible given the selected cards, both students reported: *'I made a plan to work it out.'* as their first metacognitive action. A number of other students from one classroom also reported their first metacognitive action as '*I made a plan to work it out.'* As this did not happen often in any other grade, it seems likely that students were following their teacher advice to make a plan before starting work. Given these considerations, Regulation beginnings do not challenge the model.

Another explanation for reported beginnings being other than Awareness, is that the language used on the cards did not match student thinking. This seems unlikely given:

a) the number of students who did report the use of Awareness at the beginning and elsewhere in the sequence,

b) the often reported repeated use of Awareness at the beginning of the problems,

c) responses written on blank cards did not indicate the need for further Awareness cards and

d) the expansion of cards available after initial trialling.

Data collection in this study indicated that students were able to report a whole range of metacognitive actions representing the three metacognitive functions (Awareness, Evaluation and Regulation) using the action cards.

What is the Relationship Between Cognition and Metacognition?

The question sometimes raised by researchers, even of students studying at higher levels of education, is whether students use metacognition. The data in this study is absolutely affirmative. Students reported frequent use of metacognition on every task at every school and in every class.

The question of how students use their problem solving time in regards to cognition and metacognition is interesting. Unfortunately the allocation of time to each process was not tracked in this study. A different method would be required for such research. Students sometimes seemed to 'chunk' their cognitive actions. For example, they may have used one cognitive statement to represented a number of complex cognitive acts. But in a similar way, the reported use of metacognition could also represent a number of metacognitive actions.

The expected sequence on any task would include frequent use of cognition. It could be assumed that cognition would be used after every metacognitive action. But the data shows that cognition was not reported after every metacognitive action and in fact, cognition was reported less often than metacognitive actions overall. The researcher suspects that cognition was not be reported as often as used between different metacognitive functions. In some cases there were long strings of metacognitive functions reported before any cognitive actions.

Students reported sequences and transitions of cognitive activity were quite dissimilar to reported metacognitive activity. While patterns of metacognition were detected with individual responses and across the total sample of students, no predictable patterns of cognitive use could be surmised. A predicted sequence of cognitive use could not be asserted with any confidence or supported by the data. However, over one third of the students reported using cognition similarly across each of the three tasks, perhaps representing their 'cognitive style'.

Metacognition and Success

The question of whether metacognition is beneficial to practice is generally accepted, but to what extent is metacognitive activity advantageous? It seems that regardless of how much metacognition is used, success is not guaranteed. Certainly, more metacognition does not necessarily equate with success. In this study longer sequences of metacognitive actions often ended in failure. This is not because more metacognition is likely to lead to failure but because metacognition is demanded when tasks are found to be more challenging. Therefore, less challenging tasks may be easier to complete successfully.

Schoenfeld (1985) documented protocols which demonstrated that: 'the absence of monitoring and assessment at the control level can guarantee failure in problem solving' Schoenfeld (1985 : 316). This statement seems logical enough in terms of success but is not helpful in relation to this study because all students used the range of metacognitive functions, particularly Evaluation. The data from this study is not conclusive about the relationship between metacognition and success.

Second Grounded Metacognitive Principle:

Successful Problem solving is not characterised by the use of any particular metacognitive function or sequence of functions.

Although some researchers have made links between executive control and the type of task and level of individual expertise (Wong, 1989), the data on metacognitive use in this study is so similar across sequences and tasks, that the type of task has been discounted as having any significant impact on successful problem solving or the employment of different metacognitive functions. The relationship between cognitive and metacognitive action must be considered as a possible discriminator in the successful completion of tasks. Students may not have the cognitive resources to complete the task or their metacognitive judgements may be incorrect. For example, regulation usually relies on monitoring. If the monitoring is inaccurate, this will impact upon subsequent actions.

Student problem solving is recognised as a complex interplay between cognition and metacognition (Artzt and Armour-Thomas, 1992, Dunlosky, 1998, Lester, Garofalo and Kroll, 1989, Schoenfeld, 1987, 1992). The importance of the relationship between the use of cognition and through metacognitive plans is noted by Artzt and Armour-Thomas (1992).

When the data were analysed, the metacognitive function use (amount of each function, sequence of functions, length of sequences and task type) was remarkably similar regardless of success or lack of success. The only factor which seemed to be possibly related to success was the school students attended and the class they worked in. But, given the small difference and the relatively small number of classes and even smaller number of schools involved in the study, it would be unwise to attempt to draw conclusive results from the sample.

The reader is reminded that non-cognitive factors which are often linked to successful and unsuccessful problem solving, for example, student beliefs about themselves, schooling, learning and mathematics (Siemon, 1993, Garofalo, 1989, Goos and Galbraith, 1996, Schoenfeld, 1987) have not been within the parameters of this research. Other personal attributes, for example, prior knowledge and motivation, which were not studied within this research context can impact upon students success in problem solving.

More research is needed which examines which specific metacognitive actions are likely to lead to success and the importance of the cognitive actions and other factors within the sequences. Zimmerman (1995) argued views of self-regulation need to be expanded to include the complex interaction of social, motivational and behavioral components of self-regulation.

Metacognitive Style

The notion of metacognitive style was raised after one third of the data was collected and analysed because of the similarities in the way that students worked. Total data analysis revealed that about one third of the student cohort worked in a similar way metacognitively on each task. Other students demonstrated consistent ways of working on two tasks. Further data and task analysis with individuals would be needed to make more convincing conjectures about metacognitive style. Only a brief discussion of the findings is presented here.

Third Grounded Metacognitive Principle:

Some students use a consistent way of working metacognitively which could be called 'metacognitive style'.

The data was analysed and organised so that students could be classified into 'metacognitive style types'. These were named: 'Frequent use of Regulation', 'The Evaluative student', 'revisiting Awareness' and others were classified as demonstrating 'Individual Metacognitive Styles'. The success on different tasks was calculated to enable broad statements to be made about the relative success of such styles.

While the idea of metacognitive style is fascinating, it seems logical that success would be more likely when metacognitive function use is varied and matched to the needs of the task as it progresses (see Goos, 1998). The benefits of versatility has been discussed by many researchers (Biggs, 1985, Entwistle and Ramsden, 1983, Schoenfeld, 1985). While acknowledging that the numbers of student who were considered to demonstrate a metacognitive style are small, the success rate of students who consistently demonstrated a particular metacognitive style on all tasks was marginally better than the average one third overall rate of successful completion.

Limited data is available to explain the association between success and particular metacognitive behavior. While intuitively, all metacognitive actions seem important, for example: Revisiting Awareness as needed, regular use of Evaluation and the consequential Regulatory acts, the issue of what is more important for problem solving success cannot be resolved within the scope of this study.

It has been argued that an awareness of learning styles can inform teacher practice and improve student learning:

> Knowledge about stylistic preferences is valuable in that it makes inherent biases transparent (for students and teachers), thus allowing them to capitalise on strengths and concentrate on improving (or living with) weaknesses. (Geisler-Brenstein and Schmeck, 1996 : 308).

In a similar way, if metacognitive style or preference does exist, there are interesting educational possibilities for learning. An understanding of metacognitive style could inform effective teaching and learning. Raising students awareness of learning strategies and their personal use of such strategies could improve their selection and problem solving practice.

Conclusion

Various models of metacognition has been developed during this research. Those presented here appear to be a viable representation of metacognitive functions and transitions. It is asserted that consistency in results about the nature of metacognition is not a coincidence nor is it a result of the technique used.

By examining specific metacognitive and cognitive actions (reported through the MMI), a better understanding and basis for further educational dialogue of what enhances and hampers problem solving is possible. Because of the importance of metacognition for learners of all ages and across curriculum domains, a methodologically sound assessment of metacognition has many significant implications for educators and education.

The findings in this study add detail to what is already known about the nature of young mathematicians' metacognitive behaviour. These results and the method for assessing metacognition provide benefits and opportunities for many educational stakeholders.

For **researchers** the research:

• provides further details about the theoretical nature of metacognition

• provides a technique for assessing metacognitive behaviour at a detailed level.

• could be modified for the assessment of other aspects of mathematical thinking

• could be adapted for the assessment of metacognition in other contexts

For **educators** the research:

• provides a framework for understanding metacognition

• provides a shared language for teaching about metacognition

• outlines a technique to use for the assessment of metacognition

• increases the likelihood of metacognition being seen as important in the curriculum

• provides ideas for improving the teaching of metacognition

For **students** the research:

• makes what teachers value (metacognition) visible to children

• encourages students to reflect on the process of thinking and problem solving

• models language which may be used to discuss metacognition.

If the education community considers metacognition to be worthwhile, then the assessment of metacognition is vital. This relies on a clear accepted definition of metacognition. One such definition which is based on the literature and empirical findings has been offered in this paper. It is feared that without recognition through assessment, metacognition will remain at the level of rhetoric only.

This study has tested a theory about the structure of metacognition in an empirical study of the use of metacognition by grade 6 students in problem solving situations. The data collected in this study supports the proposed model of metacognition and the legitimacy of the method by which metacognitive processes might be researched. The results of this research offer insight into metacognition as it is employed by upper primary school children. It seems reasonable to suppose that if the model were tested with adults, with appropriately challenging tasks, the results would demonstrate the use of similar sequences of metacognitive functions.

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Appendix Action Statements

Metacognitive action cards:

I thought about what I already know (Awareness)

I tried to remember if I had ever done a problem like this before (Awareness)

I thought about something I had done another time that had been helpful (Awareness)

I thought 'I know this sort of problem'(Awareness)

I thought 'I know what to do' (Awareness)

I thought 'Is this right?' (Evaluation)

I thought 'I cant do it.' (Evaluation)

I thought about how I was going (Evaluation)

I thought about whether what I was doing was working (Evaluation)

I checked my answer as I was working (Evaluation)

I made a plan to work it out (Regulation)

I thought about a different way to solve the problem (Regulation)

I thought about what I would do next (Regulation)

I changed the way I was working (Regulation)

Cognitive action cards (logic and number tasks):

I asked for help

I drew a diagram

I read the question again

I added

I subtracted

I multiplied

I divided

I counted

Cognitive action cards (tangram task):

I tried to see if a shape would fit

I moved a shape around

I turned a shape over

I tried a different shape

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