Metacognitively ALERT In Science

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Abstract

The development of student metacognition has the potential to provide some of the greatest learning gains in science classes, even outstripping the contribution of general intelligence. However, some science educators not only struggle with successfully prompting students to develop metacognition, but also find understanding the concept itself problematic. This struggle is compounded by models for metacognition that are in broad agreement about its nature, but vary widely in essential elements and the relationships between elements. This article presents a synthesis of metacognition studies in science education and further afield that draws together non-contested elements into a readily understood hierarchy of metacognitive knowledge and skills. The hierarchical framework comprises, from the foundation level, self-Aware of cognition, self-Monitor cognition, self-Evaluate cognition, self-Regulate cognition and self-Transfer cognition (AMERT).

As a preliminary test of its viability, the AMERT framework is used to analyse interview data in which there was evidence of rich metacognitive thinking by students in the fourth, research-focused, year of a science degree. The degree used the six facets of the Research Skill Development (RSD) framework as labels for cognition. Rich epitomizing statements were found in interviews for each level of the AMERT hierarchy, providing tentative evidence of its viability for understanding metacognitive processes. The AMERT hierarchy of metacognition provides opportunities for teaching and learning, teacher action research, and research teams to investigate metacognition in the contexts of school and university science programs.

Introduction

In its recent resurgence, research on metacognition has claimed for it a number of educationally important characteristics that make its investigation a priority in science teaching and learning. Many studies have shown the potential benefits of well-facilitated metacognition for learning and problem solving in science (Schraw et al., 2006; Taasoobshirazi & Farley, 2013; Thomas, 2013; Adler et al., 2016; Zepeda et al., 2019). Recent studies have shown substantial gains in learning due to metacognition across primary, secondary and tertiary years, including: between primary mathematics classrooms where the metacognitive talk was stronger versus those where it was weaker (Smith & Mancy, 2018); in High School Physics, where student metacognition measures correlated with higher levels of performance (González et al., 2017); and in Chemistry classes for those in initial teacher education (Adadan, 2020). For example, after inquiry-based instruction, High School participants with high-level metacognitive knowledge, when compared to participants with low-level metacognitive knowledge, were more likely to change their conceptions to science-oriented ones (González et al., 2017). Additionally, the participants with high-level metacognitive knowledge developed a more coherent and consistent understanding of lunar phases and gas behaviour, and retained their scientific understandings months after instruction (González et al., 2017).

The importance and benefits of metacognition are mirrored in recent studies that are outside Science Education, but relevant to it: student metacognition is vital for design thinking, including experimental design (Kavousi et al., 2019); metacognition is beneficial across learning in schooling and university (Perry et al., 2019); and metacognition is vital for problem-solving involving the ‘extensive entanglement between metacognition and manipulation in working memory' (Shea & Frith, 2019, p. 568). A synthesis of meta-analysis of metacognition studies asserted that some facilitated metacognitive strategies doubled the expected amount of learning of students when compared to standard instruction (Hattie, 2008; Hattie & Zierer, 2017). Moreover, earlier research claimed that metacognition promises a more substantial contribution to learning than general intelligence (Veenman et al., 2004, p. 92). The ubiquitous agreement about the nature and potential of facilitated student metacognition for learning gains, however, disguises disagreements about specific features of metacognition and its measurement.

Definition Of Metacognition

There has been broad agreement on what comprises core components of metacognition including across school and university study (Lai, 2011). In general terms, metacognition is the form of cognition whose subject is cognition (Acar, 2019). Ongoing agreement concurs with Flavell's (1976) early characterization that metacognition consists of metacognitive knowledge and metacognitive experiences and that metacognition 'regulates any aspect of any cognitive endeavor' (p. 906). A study set in high school physics similarly operationalised metacognition as 'two stages: First, an *awareness of certain skills* or strategies and resources to perform certain tasks effectively; second, the ability to *use self-regulatory mechanisms* to ensure the successful completion of that given task' (Wade-Jaimes et al., 2018, p.715). Self-awareness of cognition, used synonymously with metacogntive knowledge, and self-regulation are repeated, non-contested, themes in the literature on metacognition.

Metacognition includes a learners' inner awareness about their content knowledge, learning processes, current cognitive state (Hennessey, 2003) and 'management of one's own thought' (Kuhn & Dean, 2004, p. 270). Metacognition comprises processes about person, task, and strategy, as well as declarative, procedural, and conditional knowledge (Flavell, 1979). Cognitive strategies are used for complex activities such as problem solving or planning tasks, whereas metacognitive strategies are employed in order to self-monitor, self-evaluate, control and understand the cognition used during those complex activities (Panahandeh & Asl, 2014).

Recent exploration showed the primacy of the affective domain to enable higher levels of metacognition, such as self-regulation (Author). There is a strong and integral affective element to cognition and metacognition, however affect is outside of the scope of this current article. Research has also explored group metacognition (Smith & Mancy, 2018) but this too sits outside of this current article's focus on individual metacognition.

Problems With Metacognition

Despite the potential, the advantages of metacognition may be overstated due to problems associated with measurement (Akturk & Sahin, 2011), and these are, in large part, due to the lack of agreement on specific aspects of metacognitive models (Azevedo, 2020). Some of the problems with metacognitive models and measures lie with conflating non-metacognitive elements with metacognitive ones and there are different problems associated with the relationships articulated between metacognitive elements.

Metacognition's role, processes and elements

Metacognition is frequently conflated with other forms of complex cognition. A recent commentary on the ongoing 'discussion in the field has been the complex interaction between cognition and metacognition that continues to challenge researchers … This represents a dilemma of having a higher-order agent overlooking and governing the cognitive system while also simultaneously being part of it' (Azevedo, 2020, p. 92). One controversial aspect of that dilemma concerns the status of metacognition as an order of thinking that is higher than other forms of cognition. When metacognition is activated, its role is to understand, diagnose and govern other forms of thinking. However, there are times when learners are not, and need not, be metacognitive, so at those times other forms of cognition have a priority, for example, due to the limited capacity of working memory (Martinez, 2006). In terms of governing thought, metacognition may be called higher order, but in terms of processes, it is not higher than other forms of cognition. For example, analytical processes are used during cognition and metacognition: for cognition the analysis is of external phenomenon, whereas for metacognition it is of the internal world of one's own thinking and sentiments. Metacognition seen as higher-order-thinking is an emphasises on the *role* of metacognition to *govern* cognition, like a 'top layer' of cognition, an idea evident in a hierarchical model for cognition (Kayashima et al., 2011). The higher-order perspective is useful to understand what metacognition does, but not its mechanisms or how it may be developed. The framework presented below focuses on the cognitive processes that comprise metacognition, rather than its role.

Any framework for, or measure of, metacognition must consider aspects that are genuinely metacognitive only. Including non-metacognitive elements in metacognitive models compromises construct validity and therefore affects measurements in questionnaire design and observation studies that are based on those models. A commonly used, efficient method of evaluating metacognitive skills is self-report questionnaire, however there 'is a wide range of questionnaires that measure a variety of components of metacognition' (Craig et al., 2020, p156), and the variation flags uncertainty about the construct validity of such surveys. As an example of including non-metacogntive elements, one study's Likert scale items that were used to measure metacognitive knowledge included 'I really pay attention to important information' (Acar, 2019, p. 658). Paying attention to important information may be a measure of metacognitive knowledge, but could just as easily be interpreted as learning for the test and lacking in metacognitive characteristics.

Observation-based research too seems to include non-metacognitive elements. In a well-cited study employing observation-based research that used quantitative measures for metacognition, the 'frequency of scrolling back to earlier experiments' was used as 'a positive indicator of metacognitive skillfulness' (Veenman et al., 2004, p. 98). Therefore, a student who did not scroll back to previous experimental data was measured on this item as having lower metacognition than a student who did. However, some students who did not scroll back may not need to because they deeply understood the experimental design or numerous other possibilities which may not relate at all to metacognition. The same study (Veenman et al., 2004) characterized hypothesizing and drawing conclusions as metacognition. However these sophisticated forms of thinking are forms of cognition not metacognition, for student awareness or control of thinking processes do not, by default, occur when hypothesising or drawing conclusions. Wade-Jaimes, et al., (2018, p.718) states that the teacher 'would ask *metacognitive questions* that require the student to make predictions about a novel circuit configuration, such as "What will happen in the circuit when you add/remove this component?"' Predicting the results of removing a component is a focus on the phenomena, not on students' cognition and therefore does not necessarily prompt student metacognition.

Relationship between metacognitive elements

Another common feature in the literature is the unclear relationships between metacognitive elements. While '… the majority of researchers separate metacognitive knowledge from metacognitive skills' (Perry et al., 2019, p. 485), the separation does not indicate the relationships between them. Moreover, metacognitive elements are sometimes represented as phases (e.g. Azevedo, 2005) implying a linear sequence that may be true for the role of metacognition but is not true of metacognitive processes.

When considering the processes, there is an unambiguous dependency of metacognitive skills on metacognitive self-Awareness: without metacognitive self-Awareness, cognitive skills necessarily function without the 'meta' component. To be metacognitive, these skills must operate within an awareness of cognition as a pre-condition. For example, high-level evaluation, is not dependent on metacognition, however, self-Evaluation of cognitive performance is a metacognitive skill because it is focused on cognition itself, enabled by self-Awareness. A comprehensive framework (Tarricone, 2011) clearly distinguishes between metacognitive knowledge and skills (Azevedo, 2020) by representing skills in parallel to, but not intersecting with, metacognitive knowledge. However, this clear distinction does not demonstrate the connections that exists between metacognitive knowledge and skills, leaving a need for clarification about the relationship between them (Bannister-Tyrrell et al., 2014), a clarification that may provide insight into the development and understanding of metacognitive processes.

Fundamental Construct problems

To deal effectively with the dilemma and problems above, theoretical progress in the field of metacognition has been called for before further data is generated (Sobocinski et al., 2020). Without a sound theoretical model, measures of, and outcomes attributed to, metacognition may be over-estimated due to the reliance on quantitative data generated with instruments that have debatable construct validity. In the rush to quantify and generate generalizable results and guidelines, there may have been and continue to be measures of metacognition that are not valid or reliable. The lack of clarity is amplified by the many different terms that are used to indicate metacognition, and include, but are not limited to, metacognitive awareness, metacognitive knowledge, higher-order skills, thinking strategies, learning strategies, self-control, self-regulatory strategies, and monitoring of comprehension (Veenman et al., 2004). The different terminology and measures add confusion to understanding of the nature of metacognition.

Some science education studies have recognized the limitations in terms of measuring interventions on metacognition. For example, a study set in junior high school physics classes that were using 'metacognitive tools' returned ambiguous results in short-to medium timeframes, finding that 'students most likely failed to either deeply process the information provided during metacognitive training and were either unable or unwilling to apply this knowledge to their learning supported by the simulation.' (Moser et al., 2017, p.959). The study concluded that 'Further, training over an extended period of time might have been beneficial' (Moser et al., 2017, 959). The study's negative finding of the short-term use of metacognitive tools in science education either provides a cue about time for development of metacognitive skills, or that the training, measures or constructs it was based on are faulty.

The need for theoretical progress in the field of metacognition and the lack of clarity about the constructs for and the measurements of metacognition has led quantitative researchers in science education to call for deeper understanding of metacognition through qualitative studies that capture detailed and fine-grained data (Gonzalez et al., 2017; Adadan, 2020). Data comprising interviews with students who have rich learning experiences can provide some of that detail and nuance (Adadan, 2020).

To summarise, a clearer framework of metacognition is needed that must 1) deal with metacognition only, 2) show the relationship between elements and 3) provide insights into rich qualitative data before it may be further tested with quantitative studies. This paper addresses these gaps through its two aims. The primary aim is to present a synthesis of common elements in the literature into a viable framework of metacognition. The secondary aim is to conduct a preliminary test of the viability of the framework to articulate the nature of metacognition as determined by its capacity to generate analytical insights into rich qualitative data. A theoretically sound and empirically-viable framework of metacognition could better inform teachers about facilitating student metacognitive learning and enable researchers to probe metacognitive aspects of teaching and learning.

The empirical data to test the framework's viability comes from interviews with Bachelor of Animal Science students in the final year of a degree that used the Research Skill Development (RSD: Author: see Appendix 1) framework to conceptually frame teaching, learning, and assessment in pertinent courses across the degree (Author). The RSD articulates six facets of research thinking, which are represented in this paper as verb-pairs linked by an ampersand: embark & clarify, find & generate, evaluate & reflect, organize & manage, anlalyse & synthesise and communicate & apply (see Author for details). The interview data was deemed to be appropriate for the testing of the viability of the metacognitive framework due to its similar status to data from a qualitative study of RSD use across a Medical Science degree (Author). In the latter study, evidence emerged that student metacognition was substantially developed by repeated exposure to the RSD framing of teaching, learning, and assessment in several, diverse units of study. However, no detailed analysis of metacognition was conducted in that study due to a lack of appropriate framework (Author). The analysis of the Animal Science student interview data in this current article, using the hierarchical metaphorical framework, is a step towards to determining the viability of the framework. The next section outlines the synthesis of this framework of metacognition, followed by the context and methodology of the empirical study that tested the viability of the framework, and then results, discussion and conclusions.

Amert Framework Of Metacognition

No one metacognitive framework provided the analytical insight into the graduate interview transcripts. Therefore the research team:

- Identified non-controversial elements of metacognition that were prevalent in the literature
- Excluded those elements that were not metacognitive by default, such as hypothesizing and planning.
- Identified where pre-conditions are necessary for an elements of metacognition to be realized.

The metaphorical framework described below emerged from these processes to identify and relate metacognitive knowledge and skills.

Metacognitive Skill Hierarchy

Building on the foundation of metacognitive knowledge, commonly called self-Awareness, as a pre-condition for metacognitive skills, there is an articulated relationship among the metacognitive skills in the literature that is hierarchical in nature. While not all recent research agrees with a hierarchy among metacognitive skills (e.g. O'Leary & Sloutsky, 2019), it is broadly understood that 'monitoring of cognition plays a causal role in self-regulation of cognitive processes' (Rhodes, 2019, p.168). Monitoring of cognition is then a pre-condition for self-regulation of cognition, and such monitoring must be áppropriate for self-regulation to be effective (Mueller et al., 2016). In turn, for monitoring to be accurate it is based on the metacognitive knowledge that comprises student self-Awareness of cognition. A recent literature review of metacognition in primary and secondary school contexts delineated metacognitive skills commonly used by educators who:

… include strategies that help pupils to *monitor, plan, evaluate* and *regulate* … as well as strategies that consciously help pupils solve *novel* problems (Perry et al., 2019, p. 486).

This quote provides a consolidated list of practitioner-oriented metacognitive skills: monitor, plan, evaluate, regulate and solve novel problems. The list is similar to that from research finding from primary school science metacogntion (Georghiades, 2004). 'Solve novel problems' is here called cognitive *Transfer* as it is the standard term in the literature on metacognition (Ford et al., 1998; Smith et al., 2007; Heggen, 2008). Moreover, 'plan' in this paper is portrayed as an aspect of self-Regulation of cognition (as discussed below). A similar list at university level is monitor, evaluate, control and understand the cognition used during those complex activities (Panahandeh & Asl, 2014, p. 1409-10). Here control, as a parallel term to regulate, is for these authors an umbrella terms that covers transfer. Metacognition is not portrayed in the literature as qualitatively different across schooling and university (Perry et al., 2019).

The 'causal' connections, or more accurately, the preconditional processes, make for a hierarchical relationship between the elements of the framework introduced next. The elements of metacognition are, in order of hierarchical sequence, self-Aware of cognition, self-Monitor cognition, self-Evaluate cognition, self-Regulate cognition and Transfer of cognition (AMERT). In the AMERT hierarchy, higher levels occur on the basis of lower levels and depend on how effectively these lower metacognitive processes are functioning and remain functioning. This is the same sense as Maslow's hierarchy of needs (Maslow & Lewis, 1987) where the lowest level of 'physiological needs' is not only a pre-condition for all higher levels to happen effectively but is also a co-condition that must remain in place. The AMERT hierarchy of process means that self-Regulating cognition is ineffective without self-Evaluating and self-Monitoring cognition which in turn are ineffective without being self-Aware of cognition. This hierarchy does not mean a sequence of steps up, such as first being self-Aware then self-Monitoring then self-Evaluating. Rather as a higher level on AMERT operates the lower levels also operate simultaneously, i.e. self-Evaluating cognition does not happen without self-Awareness of cognition and self-Monitoring cognition occurring at the same time. Regulation of *cognition* happens all the time at a level below conscious control, but self-Regulation here is intentional, metacognitive and reliant on the lower levels of the hierarchy.

A specific form of self-Regulation of cognition is the intentional Transfer of cognitive skills from one context to a less familiar context. Cognitive transfer is seen to be an outcome of active self-Monitoring (Perkins & Salomon, 1992) and self-Regulating (McKeachie, 1987). In this current article, Transfer of cognition is regarded as such a specific and difficult form of regulation that it is placed at the top of the AMERT framework, directly above but connected to self-Regulation of cognition. Moreover, the concept of planning cognition is treated in AMERT as a form of self-Regulation of cognition, in keeping with a literature review on metacognitive thinking (Lai, 2011). Planning cognition for tasks that are relatively close to other experiences is called *near* Transfer of cognition, and planning for unfamiliar tasks is *far* Transfer of cognition (McKeachie, 1987). While planning cognition is often placed as an early phase of metacognition, this is a focus on the *role* of metacognition to govern cognition; AMERT's focus on process represents planning as part of the self-regulating process which relies on the lower levels of the framework to be effectively activated.

Amert Hierarchical Framework

Each level of AMERT is expounded in the following section.

Self-Aware of cognition

Self-Awareness of cognition involves students knowing what they already know and especially a realization of the processes and skills involved in cognition (Efklides, 2008). The conceptual power of all forms of metacognition is dependent on the quality of the metacognitive knowledge that students are self-Aware about. As students become aware of their cognitive processes, their knowledge may be trivial, minimal, incorrect or incoherent if it is not introduced and supported expertly. Self-Awareness implies self-articulation of the internal realms of thinking and benefits from appropriate and communicative labels for different kinds of cognition (Cellar & Barrett, 1987).

Teaching metacognitive self-Awareness can involve making explicit such cognitive labels which become a 'metalanguage' that facilitate student self-awareness (Cellar & Barrett, 1987). Cognitive labels name cognitive processes and so enable awareness of one's own thinking, a requirement for metacognitive knowledge. Cognitive labels may be formed by the learner herself as her pre-verbal, core metacognitive knowledge emerges and becomes explicit (Goupil & Kouider, 2019), or may involve labels imparted by siblings, parents, or teachers. The student interviews below are from a program that, in effect, used the RSD facets as cognitive labels. Cognitive labels must be internalized to effectively become metacognitive self-Awareness of cognition, i.e. there must be a development from labels given, say by a teacher, to a deeper understanding by the students (Cellar & Barrett, 1987). Teacher impartation of cognitive labels may be a good beginning, but it may be a long way from student self-Awareness, especially if there is dissonance between the students' existing knowledge of their cognition and the teacher's labels. Moreover, what a teacher means by a label may be very different to the understanding of that label that each student constructs.

Self-Monitoring Cognition

Self-Monitoring draws on student self-Awareness of cognitive activities to explicitly gauge what thinking is currently taking place. Self-Monitoring will be off-track and impractical if an individual's own cognitive labels are not functional or students have a shallow understanding of appropriate labels. Self-monitoring activates thought processes that encourage critical thinking in the student (Facione & Facione, 1996), so without self-Monitoring, there is no internal data for effective self-evaluation of cognition. Therefore, self-Monitoring is foundational to, and precedes or occurs simultaneously with self-Evaluating in AMERT. Self-Monitoring indicates where a student is currently at cognitively, which includes the ongoing process of checking progress towards a set goal (Pintrich, 1999) and whether a specific reference point is reached during self-regulation towards some cognitive location (Zimmerman, 1995).

Self-Evaluation of Cognition

Self-Evaluation of cognition involves decisions about whether current cognition is good enough to get the job done based on each student's thinking patterns (Elder & Paul, 2004). The information on which to make such judgements is provided by self-Monitoring of cognition and provides the data for self-Evaluative contrast and comparison. The contrast between where one is cognitively and where one needs to be provides the internal, self-Evaluative impetus for a change in cognition that involves self-Regulation. Comparing current cognition and perceived needed cognition provides a realization of insufficiency if cognition doesn't or wouldn't get the desired outcome, or of adequacy if it does.

Self-Regulation of Cognition

Self-Regulation of cognition is typically characterized as a change that works to improve or optimize student learning processes (McInerney et al., 1997). However, self-regulation involves not only intentional change but also intentional maintenance and consolidation of currently effective cognitive strategies, especially when managing one's behavior and undertaking tasks to achieve an intended goal, process, or desire (Efklides, 2008; Samsonovich et al., 2008). Self-regulation involves ideation of, or planning, a desired cognitive place to be (Efklides et al., 2001) and volition to go or stay there. When current cognition is self-Evaluated and found to contrast with ideated cognition, this provides the impetus to self-Regulate cognition in that new direction.

The consolidation aspect of self-regulation is as crucial as the change aspect and involves a process whereby self-evaluation suggests present cognition is ideal or fit-for-purpose, resulting in an active decision to uphold cognition, to stay at present, optimum levels (Zimmerman & Schunk, 2011). Such an intentional stabilization of cognition, for example maintaining cognitive focus (Efklides, 2008; Samsonovich et al., 2008), may be a factor in maintaining immersion in learning, or 'flow', by the learner's intentional removal or reduction in factors that could otherwise distract from the present fluid cognition (Landhäußer & Keller, 2012). Cognitive flow is by nature primarily unaware of all but its focus subject, not typically metacognitive, however, maintaining flow may sometimes require subtle self-monitoring of shifts away from the flow as well as self-regulation back into the flow.

Self-regulation of cognition relies on information from self-Evaluation of cognition in order to activate conscious control of cognition and to adapt cognitive functioning appropriately. Self-Monitoring and self-Evaluating cognition are precursors to, and co-conditions of, self-Regulating because intentional changes in thinking processes cannot be made effectively without knowing what is already happening cognitively. Self-regulation without self-evaluation during a cognitive task is like running in the dark; unaware and potentially leading to a fall.

As noted earlier, planning of cognition is not a separate component in the AMERT framework but is rather subsumed in self-Regulation of cognition. Planning is often characterized as a metacognitive first 'phase' but a phase orientation is a focus on the role of metacognition rather than its processes. Planning cognition is complex, requiring co-occurring self-Monitoring and self-Evaluating processes (O'Leary & Sloutsky, 2019) and is related to cognitive transfer, described next.

Self-regulation may also lead to cognitive overload, impairing students in the task at hand, in part because they are allocating finite cognitive resources to think about their thinking (Sweller, 2011). Self-regulation requires self-evaluating to determine when to discontinue metacognition and focus only on the task at hand rather than one's own thinking about it.

Self-Transfer of cognition

Self-Transfer of cognition, the fifth level of AMERT, is the use of cognitive strategies that are developed in one context and employed intentionally as strategies in a different context (Tuomi-Gröhn & Engeström, 2003; Smith et al., 2007; Heggen, 2008). Transfer of cognitive skills to new contexts is not easy, because knowledge is acquired or developed in a language-and-culture-rich context, as are the metalanguages, or labels, used in metacognition (Cellar & Barrett, 1987). As cognitive skills like 'analysis' shift in meaning and nuance from context to context, the shift makes Transfer of cognition complex and for many students it requires facilitation by others.

For Transfer of cognition to occur, an individual must recognize prior cognitive knowledge and skills and how these need to be r*econstructed* or *re-contextualized* (Garraway et al., 2011) to meet the needs of the new context, by identifying what cognition is required and reflecting on any similarities to past experiences (Garraway et al., 2011). Self-Transfer of cognition is fully intentional and is an indicator of high-level metacognition in learning environments and situations that are different from where the cognitive skills were learned. The AMERT hierarchy suggests that if self-Transfer of cognition is happening effectively, self-Awareness, self-Monitoring, Self-Evaluating and self-Regulating are taking place simultaneously.

The hierarchy of the AMERT framework

The AMERT model (Table 1) shows that the lower levels, starting from self-Awareness of cognition, are pre-conditions for those above all the way to self-Regulation and its highest form, self-Transfer of cognition. Weak self-Awareness then, such as that due to the use of poor cognitive labels, drastically reduces the effectiveness of higher levels of metacognition. Moreover, students may intentionally change their cognition without self-Monitoring and self-Evaluating it, but that regulation would be uninformed, random, lack a feedback loop, and lack discernment into the current cognitive state and the effects of any changes. Change always shifts, whereas self-Regulation of cognition may involve maintenance of a steady state due to its reliance on self-Evaluation and the lower levels of AMERT.

Table 1: The hierarchical AMERT framework of metacognition

In the AMERT framework, self-Awareness is knowing about different forms of cognition e.g. 'I know about the thinking involved in analysis'. Self-Monitoring is the comprehension of one's current cognition: e.g. 'I am analysing'. Self-Evaluation is to see if cognition is sufficient or should be different e.g. 'I need to be more critical in my analysis'. Self-Regulation is to intentionally cognitively shift or to actively consolidate, whether the type, quality or intensity of cognition e.g. 'I am going to critique more from a perspective that challenges the ideas in my current analysis'. Transfer is to intentionally move previous patterns of cognition to a new context or adapt cognition to fit a new context, e.g. 'I will adapt and apply my analytical critique that I used in science investigation to my mathematics investigation.' To use an analogy with heart rate to explain the hierarchy, self-Awareness is distinguishing the sound or feeling of one's own heart and calling it a 'heartbeat'; self-Monitoring is actively taking one's pulse; self-Evaluating is comparing or contrasting the rate to where it should be, depending on rest, exercise or stress levels; self-Regulating is actively taking steps to increase, reduce or maintain heart-rate; Transfer is applying this regulating capacity to other contexts, such as a personal trainer might with a client. An ineffective label that would lead to poor self-Awareness, in this analogy, is exampled by the term 'liverbeat', which would render all the higher levels misleading.

An example applied to AMERT

Two quotes from a study that suggested metacognition due to RSD use across a program, but did not have available an appropriate metacognitive framework to probe this in detail, will provide an example of the use of AMERT to unpack metacognitive statements:

… you can see all the levels; you can see where you are. You compare yourself to the data. It takes a skill to be honest to yourself; that's the first skill. When you look at the different levels, you can see where you are fitting and then you look at the levels ahead, at what are your areas of improvement so you can improve yourself (Author).

- Self-Aware: … *you can see all the levels*
- Self-Monitor: … *you can see where you are fitting*
- Self-Evaluate: *You compare yourself to the data. It takes a skill to be honest to yourself…. then you look at the levels ahead, at what are your areas of improvement.*
- Self-Regulate: … so *you can improve yourself*

So *you can improve yourself* has a strong planning sense and the potential for transfer to new contexts.

Self-Transfer is explicitly noted by another student in the same study: '… because they have been consistently applying this structure to all of our assignments, we have come to think that way for science (Author). This is a transfer from the range of specific assessment tasks to a scientific way of thinking more globally.

AMERT is an interpretation and synthesis of the findings on metacognition over the last four decades, however, how effectively does this hierarchical framework represent metacognition? Using López-Campos et al's. (2008) framing, three questions need to be answered before AMERT framework should be used broadly:

1. Does the AMERT framework provide a *viable* interpretation of accounts where metacognition is evident? (Framework is functional and provides insight.)
2. Does the AMERT framework provide a *valid* understanding of metacognition? (Framework has construct validity.)
3. Do AMERT-based instruments provide *reliable* scores of metacognition within and between studies? (Framework informs instruments that demonstrate internal and external reliability.)

In terms of viability, is the framework functional, easy to interpret and readily able to help researchers distinguish different levels? Testing of viability may be done with rich qualitative data, so see if the different levels correspond to actual experiences. Researchers from outside of the team that formulated AMERT are need to also test viability, before further testing of validity is warranted. Testing the construct validity requires using AMERT a priori as the framework to generate data. However, it would be premature to devise a priori empirical tests given the calls that proritise deep qualitative understanding and the need to devise better theorisations of metacognition before further data is generated, as mentioned earlier. Therefore, the general question addressed by this study concerns viability only:

Does the AMERT hierarchy provide a viable understanding of student metacognition that is evidenced in interviews?

Context And Methods

The empirical element of this study, which addressed its secondary aim, considered student metacognitive outcomes of explicit research skill development and assessment across a science degree. Determining the congruence between student accounts of this development and the levels of the AMERT framework provided a small but important test of the hierarchy's viability.

Study Context

The Bachelor of Animal Science is a three-year degree, with an optional fourth, research-focused year, taught in a regional campus of an Australian Research University. Before the study, one course in first year began using the RSD for teaching and learning and to frame assessment tasks, followed subsequently by two second year courses. In these courses, the RSD facets were used repeatedly to facilitate the development and assessment of the skills associated with research and so were used like cognitive labels.

This repeated exposure in different course contexts and different ways of being operationalized yielded an opportunity for the facets to be internalized by students and become cognitive labels that were deeply understood and so determine, heighten or clash with their existing metacognitive knowledge. Students were not exposed to RSD rubrics in the third or fourth years of the degree. The interviews in fourth year, one-and-a-half years after the last exposure to the RSD, provide a long-term retrospective by the students about the use of the RSD and enable a sense of the sustained influence of the cognitive labeling on metacognition.

A total of 41 students were invited through a third party by email to participate in the study, in keeping with the ethics-approved protocol which required no direct initial contact, and nine students (22%) agreed to be interviewed. The inclusion criterion was students enrolled in their research-oriented fourth and final year of the Bachelor of Animal Science in 2012 or 2013. Seven participants were enrolled in a full-time honors degree, one part-time while a full-time zookeeper and one participant had just completed the requirements of the degree but was still enrolled. Seven participants were female and two were male.

Research Question

Set in the research context, the general question this paper addresses was adapted to formulate the research question:

Does the AMERT hierarchy provide a viable understanding of student metacognition for each facet of the RSD as evidenced in interviews with students enrolled in the 4th year of a Bachelor of Animal Science?

Data Generation

This current study used a semi-structured interview strategy (Wengraf, 2001) to generate rich and descriptive data with thick descriptions and that are particularly suited to provide a deeper understanding of metacognition (Gonzalez et al., 2017; Adadan, 2020). The interviewer used the RSD facets as part of the interview prompts and showed students assessment rubrics based on these facets from first and second year (Hazel, 2011a; Hazel 2011b). The purpose was to clarify and make concrete the questions being asked because these facets had not been revisited for the 1.5 years prior to the interviews.

In the semi-structured interview protocol (see Appendix B), students were not asked directly to articulate their understanding of metacognition, but rather recount 'particular happenings' that reflect experiences of development and use of their research skills, where student '… choice of examples reveals essential features about their own ideas and experiences of learning' (Soini, 2012, p. 847). The process of recounting specific situations provides a more authentic reporting mechanism than explicit self-commentary on the concept of metacognition.

The semi-structured interviews were conducted face to face over a 40-50 minute period and were audio recorded on a digital device and sent to a third-party transcription service. During the interviews, the Animal Science students were shown memory prompts of assessment tasks and RSD based rubrics that were explicitly used to develop and assess research skills in Years 1 & 2 of their degree (Hazel, 2011a; Hazel, 2011b). Interviews were conducted by a research officer who was experienced in engaging students and eliciting deep understanding in interview situations. The 15 questions (Appendix B) related to the development and use of research skills.

Data analysis

To address the research question about viability, evidence of each level of the AMERT framework and relationships between them were sought in the interview data. The six cognitive labels of the RSD were used in the Animal Science degree and prompted in interviews, and so the RSD facets were used to organise the analysis of the transcripts. Whiting's (2008) framework for semi-structured interviews guided the analysis conceptually and it followed the protocol developed by Author (date) specifically:

- Researcher team members (Authors 2-7) were allocated one RSD facet each as a focus
- In order to provide time for deep and focused reading, one interview per week was coded by each research team member with reference to their allocated facet.
- The majority of statements were not metacognitive in nature, but were rather about what students did, and were excluded from categorisation as metacognitive,
- Statements perceived to have indicators of metacognition were coded by each team member with reference to the levels of AMERT.
- At weekly research team meetings lead by the first author, each person presented their two layers of coding for their facet, and disagreements around coding were negotiated until consensus was reached, as per Whiting (2008).
- The most indicative, or epitomizing, statements for each level of AMERT was chosen to represent that level in the results, facet by facet.

The data selected indicated if metacognition at each level of the hierarchical framework was evident across these nine transcripts, providing a sense of the 'possibilities' (Peräkylä, 1997; Talja, 1999) of metacognitive experience as framed by AMERT. Statements deemed to epitomise a specific RSD facet at a specific level of AMERT were often chosen because they were communicative for differentiating between the different level of AMERT. Moreover, statements chosen tended to have phrases that were on several levels of the hierarchy, and this helped provide a sense of the hierarchical relationships.

Statements that epitomised different levels of metacognition were sought from the interview data because these epitomising statements provided an opportunity for reducing ambiguity, increasing clarity and providing a sense of viability of AMERT. The data is best-case scenario: epitomizing statements from students who chose to be interviewed, from a cohort who chose to do the fourth research-intensive year. Therefore the following results elucidate AMERT but do not provide a sense of how effectively student metacognition was elicited in the program. As stated above, the primary purpose of this analysis is to determine if AMERT is a viable framework for understanding metacognition.

Results

Overview Of Findings

Statement were found for each RSD facet at the self-Aware, self-Monitor, self-Evaluate and self-Regulate levels. However, the statements that were at the level of self-Transfer were more generalized in nature, did not clearly fit with the RSD facets but did fit with simple demarcation in the literature as 'near' or 'far' Transfer (McKeachie, 1987).

Epitomising Statements For Amert In Each Rsd Cognitive Label

Embark & clarify as a cognitive label

There are numerous ways to embark, but for the Animal Science degree it included formulating research questions, hypotheses, project aims or synonymous aspects that provide direction:

I think you're aware of it, but as I say, I think in first year you don't really understand what it means, like how to embark on inquiry and all of that sort of stuff; you're not really sure where you're going with it. But yes, it stayed the same. By third year, you know much more what you need to do. It becomes a lot clearer as you go on, yes. In first year you're aware of it, but I just don't think you understand it as well as you do by third year. (Student 7).

Student 7 realized that, initially, she did not understand what was expected in assignments and that she didn't have the full capacity to embark on inquiry or clarify the required direction. The statement implies that the cognitive label of *embark & clarify* was, for her, just that: a label which did not raise initially a foundational self-awareness of her cognition. Self-Awareness is demonstrated in the statement 'you *know much more* what you need to do… *I just don't think you understand it as well as you do by third year*'. The growth from first year to third year in metacognitive knowledge epitomizes the shift from a cognitive label to self-Awareness of skills of how she may embark & clarify.

Self-Monitoring is shown when the student thought that her cognitive capacity to embark *stayed the same* for some time, then as the student kept self-Monitoring this cognitive skill, by her third year she found that the process of embarking *becomes a lot clearer as you go on.* Self-Monitoring was the metacognitive process that *recognized* the shift over time, but did not drive, direct, or guarantee it. To say it *becomes a lot clearer*, rather than say, *I made sure that I clarified*, provides a passive sense that this just happened to the student over time. In terms of hierarchy, when self-Awareness of the processes around embarking, such as posing hypotheses or framing questions, emerged over time, then self-monitored realizations, such as *it stayed the same* and *a lot clearer*, became possible. The quote implies a dynamic hierarchy, where there is a sense of a mutually enhancing cycle which is not only based on self-Awareness, but also reinforces it.

In terms of cognitive self-Awareness and self-Monitoring being foundational to higher levels, one student stated:

[Without the RSD labels]… I'd say that maybe you wouldn't really know *where you're meant to be headed* towards in terms of development. You might end up just *going around in circles* and *not pushing yourself further to go to a higher level*. (Student 6).

Self-Evaluation of cognition is shown when Student 6 contrasts *going around in circles* to a desirable cognitive *higher level … where you're meant to be.* The student contrasts being conceptually stuck in a holding pattern with something *higher*, which implies the need to move to the next conceptual level, which may be more rigorous or richer experience, broader or deeper knowledge. For Student 6, this self-Evaluation of cognition provides the impetus for change. Self-Regulating the complexities of *embark & clarify* are demonstrated by the movement of intentionally *pushing yourself* to actually *go* to a higher level. While self-monitoring provides a sense of what is going on cognitively and self-evaluation provides the contrast with how things could be, self-regulation makes the shift happen. Self-regulation of cognition has a built-in planning aspect because it is always an intentional shift or an intentional consolidation. The student's self-Regulation couldn't lift her *higher* without knowing just how high she was already, evidencing that planning cognition, as a form of self-Regulation of cognition, for Student 6 was dependent on self-Monitoring and self-Evaluating cognition.

Find & generate as a cognitive label

This RSD facet involves generating one's own data or, in this case a process for finding others' information:

I already had the knowledge of where to go and look for information and how to sort of write scientifically, to a degree, yes, whereas everyone else was coming from school and didn't have that background. So I was ahead to start with, yes. (Student 5)

Self-Awareness for find & generate is shown by Student 5's knowledge of information search skills, and self-Monitoring demonstrated by her statement that she *had* that knowledge. Student 5 Evaluated her capacity to find with reference to her perceptions of its relative lack in other students: being *ahead to start with* implies a comparative look, not of her own need to improve but perhaps the opposite, a kind of self-Evaluation which confirmed a sufficient capacity. This self-Evaluation could prompt underperformance if it was not well-tuned to disciplinary standards.

In terms of self-Regulating cognition, Student 2 said of data generation:

It's basically making sure that the method you've actually got to correct for finding out the data that you need to answer the hypotheses, it's important that you can actually collect the data and put it into a spreadsheet and just keep it somewhere where you can make sense of it. (Student 2)

Student 2 recognized that utilizing the most appropriate method is imperative for generating data that tests a hypothesis. If self-Evaluation of cognition by *making sure* shows a paucity of process, then the student saw that they should *correct for* the methods, refreshing the methods themselves, or at least be aware of limitations and account for them. If the data that they were expecting was not generated, as determined during analysis, the student could then take active control, self-Regulating their cognition about the data generation method so that they could *correct* it and obtain appropriate data.

Evaluate & reflect as a cognitive label

Like other RSD facets, evaluate & reflect are skills which are cognitive in nature until the skills themselves become subject to inspection and so enter the metacognitive realm, as one student realized:

… not just this year but previous years, what they try and get you to do is to critically assess the different literature, not just kind of recite it but rather point out any potential arguments. I think where there are arguments in the knowledge, I think that's applicable. (Student 6)

Self-Awareness of evaluate & reflect is demonstrated by *what they try* is for you to *critically assess*. Student 6 appreciated the difference between teacher facilitation and self-Monitoring when you do *critically assess… not just recite.* The student self-Monitored her capacity and reflected that it was in development *not just this year but previous years*.

Student 9 grappled with the status of data she generated on a topic that she had opinions on:

… one of my biggest things is I need to step back and not pick a side, and not be biased in it. Because of the topic that I chose, I already have preconceived ideas when I'm actually collecting data, it's kind of changed my mind a bit, as well as it's probably better to stay at the back a bit (Student 9).

This quote demonstrates the same internal process of *evaluation* in terms of cognition and metacognition. The cognitive process is shown by the student evaluating her data collection. The metacognitive is shown when she self-Evaluates the cognitive process as shown by the realization that *I already have preconceived ideas*, and the alarm bells go off as *biased*.

The student knows bias will lead to poor evaluation of the topic and so self-Evaluation of cognition triggers the impulse to self-Regulate, where to *step back* is an intentional regulatory shift to gaining a more distant, broader perspective and a more objective one. Student 9 articulates that self-Regulation to produce cognitive movement is needed when she is evaluating, because self-Evaluation of her current stance shows a position that is too close, with preconceived ideas and bias. The student can recognize the risk of being too close and choose not be dominated by the bias. She actively self-Regulates to reduced bias by conceptually moving further away.

Effective self-regulation also necessitates self-Evaluating the new cognition resulting from any cognitive movement to determine if the new cognition is appropriate, and so maintain or potentially enact further change to match the chosen position. *Stay* implies self-Monitoring and self-Evaluating to ensure 'no movement' once the student's evaluation of the topic is self-Regulated to the correct, removed, location. Self-Regulation for Student 9 is not always about change and movement, then, but also may involve consolidation, requiring self-monitoring to ensure no movement from the perceived optimum position *at the back*.

Organize & manage as a cognitive label

Focusing on managing their research project, Student 5 stated:

… you still know how to look up what needs to be looked up, or fix a problem, or work through a problem with yourself, and seek help *when you need it. (Student 5*)

Seeking help *when you need* it is very different from seeking help by default, or merely knowing how to seek help. It is an example of self-Awareness and self-Monitoring of the thinking required by self-management. For Student 5, it includes that *you still know how to* manage various processes, illustrating self-Monitoring of the management processes associated with problem-solving. The statement *when you need it* demonstrates a self-Evaluation that is sensitive to the change from *still know how to*, towards the need to *seek help*.

Student 6 related the benefits of managing a research assignment by checking the assignment relative to the marking rubric provided:

'I tend to sort of towards the end of an assignment go back to a rubric, something like this, and I read through them and as I'm reading them I think, yes, I've already done that, I've done that, I've done that…' (Student 6)

It is the self-Evaluating need to check that makes this student actively self-Regulate the processes of completing assignments, by going *back to a rubric* to self-organize and check the assignment. Then, in a second iteration of self-Evaluation, the student determined if each facet is completed at a satisfactory level and found *I think, yes.* The intentional and student-instigated use of the rubric as an external aid for metacognition is an example of self-Evaluation and self-Regulation built on self-Awareness fostered by the RSD cognitive labels. Rubric provision guarantees nothing, not even self-Awareness, but repeated use as evident by Student 6 may lead to self-Awareness, self-Monitoring, self-Evaluating and self-Regulation.

Analyse & synthesize as a cognitive label

In one particular assignment, Student 1 found one assessment task sequence counter-intuitive yet beneficial, where they were required to:

… collect the data and *then* make an argument out of it. It was a bit backwards to me, and I wasn't a huge fan on that. But it *did give me* the analytical skills that I needed to do that assignment (Student 1).

The student recognized a time and event that *did give* her appropriate analytical skills when looking back to a time almost two years before the interview, at learning from a specific assignment. She was self-Aware that the assignment was a source of impartation of analytical skills and, by the time of the interview she self-Monitored that she had now acquired these skills. However, she also noted that analytical thinking could operate below the level of consciousness:

' So even though I may not consciously think, okay, I need to find this knowledge, I need to read it, I need to analyze this knowledge, and find the gaps in the knowledge to develop an assignment… it will be something that I believe *will be more unconscious'* (Student 1).

For Student 1, cognitive processes made explicit and clear, as demonstrated in the first quote, could become so internalized that the self-Awareness of them became, and *will be*, implicit and *unconscious.*

Another student reflected on the need to analyse when writing:

… scientific writing was probably where I needed to *improve the most...* I've always got that in my head to go back and critically analyze, because it's easy just to quote people and to find information without actually thinking about it. (Student 4)

Scientific writing is multifaceted and a hallmark of the scientific writing process is the sophisticated analysis of data and synthesis of existing and emerging ideas. Student 4 self-Evaluated her writing and analysis based on self-Monitoring where she was and contrasting that with where she needed to be, to determine where she needed to *improve the most.* On the basis of identification of the greatest need, the student worked on self-Regulating improvement of that need. *I've always got that in my head* shows the student is self-Aware of the skills associated with analysis and self-Monitors these skills routinely. The self-Monitoring lays the basis for self-Evaluating the need to improve writing more than other aspects of her work, leading to and impelling a focus of her limited cognitive resources on self-Regulating writing and analysis to provide the required improvement.

Communicate & apply ethically as a cognitive label

The ethical dimensions of communication hit home to one student:

'… there's definitely a lot of ethical and social issues, and definitely cultural, because everyone's different on how they would perceive that. So you would have to be careful in how you would describe your opinion on whether to keep caged or not, because you could definitely offend a lot of people and make them think the wrong thing.' (Student 3)

Student 3 was self-Aware about the ethical and social issues connected to communication and had a compelling reason to engage in self-Monitoring of communication, not just to be careful about his opinion per se, but the process-oriented *how* you would describe your opinion. This was to take *care not to offend*, for example in word and picture choice or the structure of argument, and this required a careful self-Monitoring of communication processes.

In terms of self-Evaluating and self-Regulating, Student 4 said:

I like to do better than previous assignments, so if I'd seen them as linked, I would have paid more attention to the feedback that I would have gotten in order to apply it to the next assignment to try and push myself up to the higher levels.' (Student 4)

Student 4 self-evaluated when she contrasted her current performance with her ideal performance, saying *I like to do better.* This student reflected in the interview that she did not realise there was a connection between the earlier assignments in terms of the six RSD facets. Had she realized, in hindsight she anticipated using the feedback to self-regulate to *higher levels*. In applying to *the next* assignment, the student flags self-Regulation that applies to different but similar contexts, an example of self-Transfer of cognition to close contexts.

Transfer Of Cognition

Evidence for the intentional Transfer of cognition, unlike self-Aware, self-Monitor, self-Evaluate and self-Regulate cognition, was rarely explicit for each RSD facet, but was more holistic in the interviews. Student transcripts evidenced near and far transfer of cognitive skills. Near transfer (McKeachie, 1987) pertained to transfer from the first three years of their Animal Science degrees to the fourth, research-intensive 'Honours' program and far transfer (McKeachie, 1987) involved transferring knowledge from a university setting to a 'real world' situation). In both instances, the individual adapts and adjusts their knowledge and skills to a task that differs from where the knowledge originally occurred (Ford et al., 1998) where nearness or farness is determined by the extent of the difference.

Enabling transfer from university study to different university study

Student 5 noted the transferability of skills used in research design:

… designing your own research project to some degree and following that through from start to finish would be really beneficial, because then people can realize, oh, it's not just about working with mice in a lab, or working with cell cultures or that sort of thing' (Student 5).

The statement shows a realization that the design and implementation of an experiment with mice or cultures should not be the crux of the learning, but rather the cognitive processes used to manage a major project from beginning to end and then implementing these skills in other settings. Student 1 had a metacognitive realization that such cognitive development was happening throughout the university program.

It was *everything* all my assignments, all my feedback from my assignments and then the research *methodology* courses that we undertook, so *all of my skills developed* from my undergrad. (Student 1)

Student 1 was able to recognize the cognitive skills gained from every program component. That student realized the metacognitive transfer components and understood that assignments are not just another assignment, but the metacognitively exciting opportunity of further developing and self-Regulating cognitive skills. When students see cognitive skill development everywhere, it may because they are self-Aware of, understand and can use shared cognitive labels, self-Monitor and at times self-Evaluate and self-Regulate these thinking skills. The more contexts in which skill development occurs, the more blatantly they may *see it everywhere*. The metacognition then would become self-perpetuating, no longer needing educators to point out rubrics or specifics of cognition. Self-regulation enacted across multiple-contexts makes learning how to self-Transfer cognition much more likely because students can 'generalize their learning to the whole' (Adcroft, 2011) and apply their cognition in new, less familiar contexts:

… we had a lot of research-based assignments where we had to go out and design it ourselves, get the results ourselves and then write it up, and that is what I found most beneficial. *I could then apply that to stuff that I did in Animal Science degree* … you had to go out and design the project, what you wanted to find out, how you'd go about finding that out. You'd go out every week and collect your results, and then *you would sort of work them out yourself*…' (Student 5).

Student 5 realized skills developed were transferable within university study, leading to higher levels of learning autonomy in newer contexts, where the complexities of result analysis could be conducted by *yourself*.

Enabling transfer from university study to the world of work

Only one student explicitly mentioned that the learning at university could be applied in the workforce once they graduate.

'The horse assignment was good because it was a really fixed scenario that we had to write about, how to *try and correct it*, so it was something that they were *trying to get us to think more outside the university'* (Student 7).

Student 7 saw the benefit of utilizing fixed scenarios within the university environment, learning and self-adjusting their cognition to situations that they would subsequently encounter in the workforce *outside the university.* The Bachelor of Animal Science degree included cognition relating to potential actions that should be taken when encountering unpredictable animals, owners, and their behaviors. This student, reflecting on a horse assignment, showed an appreciation of the holistic transfer of cognition.

Discussion

The analysis of the interviews with nine students provides a tentative sense of the viability of the AMERT hierarchy to provide insight into metacognition. The epitomizing statements do not show how commonly students were thinking metacognitively, just that, across the nine interviews, there were rich instances of multi-faceted metacognition at each level of AMERT. These instances of metacognition do not generalize to each cohort, let alone to metacognition broadly conceived. However, the experiences from these few students resonate with and bring to life the hierarchical framework, providing preliminary evidence that the framework is viable for providing understanding of, and organizing data that is rich in, metacognitive statements.

Such evidence of viability is a small but promising step towards an empirically-validated hierarchy of metacognition for teaching and research. If further evidence of viability emerges over subsequent qualitative studies in numerous contexts studies, AMERT could then be tested as an hypothesis for metacognition in quantitative studies which test its capacity to inform valid and reliable instruments.

The limited data in the study hints at a dynamic hierarchy, where repeated exposure to cognitive labels led to a developing self-Awareness of cognition and onto higher levels of AMERT. If each subsequent level reinforces the prior levels, the basis for metacognition becomes broader and more stable, perhaps further enabling higher levels. Once the preconditions for a higher level is met, does that mean that the higher levels are more likely to emerge without needing overt facilitation? The quality of the labels and exemplars that teachers use for student metacognitive knowledge for self-Awareness may determine the extent of success of emerging student self-Monitoring, self-Evaluating, self-Regulating, and the capacity to Transfer cognition to other contexts.

This study used the RSD facets as cognitive labels and they warrant further research into their use and function for metacognition in Science education. The facets, when used elsewhere, have shown potential to assist in cognitive transfer (Author), especially in transdisciplinary STEM (Author), where otherwise the cognitive transfer process has proven to be awkward for students and teachers. This current study raises the tantilising *possibility* that if cognitive labels resonate with teachers and learners and are used on multiple occasions as thinking routines for students, the resulting self-Awareness may actualise as self-Monitoring, self-Evaluation, self-Regulation, and, ultimately, cognitive Transfer. If that possibility were affirmed by multiple studies, teachers could focus on meaningful and repeated use of appropriate cognitive labels and allow higher levels of metacognition to spontaneously emerge. Such a process treats metacognition as enabled by normal human neuro-architecture and may provide a more realistic way to facilitate higher levels of student metacognition by regular classroom teachers than overt attempts to elicit higher levels of metacognition such as self-Monitoring or self-Regulation.

The AMERT hierarchy may also go some way to explain aspects that are still debated in the literature. Concerning Flavel's original characterisation of metacognition:

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. (Georghiades, 2004, p. 372).

The confusion may not be in the term, but in the way the relationship between metacognitive knowledge and metacognitive skills such as self-Regulation were articulated, or rather not articulated. As specified earlier, the separation of metacognitive knowledge and metacognitive skills in some models led to a lack of clarity about the relationship between them. If the AMERT hierarchy ultimately proves to be viable, valid and can guide the production of instruments that are reliable, the clarity that the framework provides will help teachers and researchers engage with the term metacognition in ways that improve students' nascent metacognitive capacities.

Further research

If the AMERT framework, or an improved version of it, were validated and began to return measures of reliability in instruments that were based on it, then it could be used to determine broad and far-reaching baseline and intervention questions such as:

- To what level, frequency and extent are teachers, using a range of existing practices, developing student metacognition?
- What is the effect of a specific innovative intervention on student metacognition?

The affective aspects of AMERT were not considered in this paper, however motivation impacts metacognitive strategy use and performance (Efklides, 2011).

- How do motivational aspects of metacognition impinge on the AMERT framework?

Some of the clearest metacognitive statements at the level of self-regulation used location-based metaphors for cognition such as *step back* and *go round in circles*. It may be that explanation of higher levels of AMERT are difficult to conceptualise or explain literally. If that is the case, the use of literal survey questions will not effectively capture the nuances of metacognition, especially at higher levels. Moreover, metaphorical statements cannot be used effectively as survey items, because people's interpretation of metaphors is wide and diverse.

- What are optimum strategies for measuring or determining student metacognition?

Another line of inquiry is the explicit instruction on AMERT to determine to what extent this lifts student metacognitive capacity, if at all.

- To what extent do explicit strategies enable metacognitive skill development?

Further research and development of the concept of the metacognitive hierarchy may direct classroom practices towards students being better able to transfer their cognitive skills to near and far locations. In Table 1, the higher levels of AMERT's hierarchy represents that effective self-Awareness is a pre-condition for effective self–Monitoring, effective self-Monitoring is a pre-condition for effective self-Evaluation, effective self-Evaluation is a pre-condition for effective self-Regulation. Cognitive Transfer is a specific, even more complex, form of effective self-Regulation of cognition towards a new context.

Future research can test the hierarchical hypothesis, looking for evidence that higher levels of AMERT, such as self-regulation, are accompanied by evidence of levels that are lower on the hierarchy, such as self-Awareness and self-Monitoring. Even though a majority of researchers now appreciate a causal relationship between at least some metacognitive elements (Rhodes, 2019) not all recent research agrees (O'Leary & Sloutsky, 2019).

- To what extent is their evidence of a hierarchical relationship between the levels of the AMERT framework?

Implications for Teaching

If metacognition were expertly and effectively facilitated, student learning would be augmented by students employing the associated knowledge and strategies. The problem is such facilitation requires a deep and fundamental understanding of metacognition, which may be lacking in teachers who focus on content knowledge and technical skills, or ineffective with teachers who treat metacognition as domain-general and distinct from content. This study implicates cognitive labelling for self-Awareness as the basis of higher levels of the AMERT framework, however metacognitive labeling by teachers as a strategy to foster self-Awareness is relatively uncommon (Georghiades, 2004). Explicit cognitive labelling by teachers that ultimately enables metacognition at higher levels of AMERT may make a realistic and seismic shift in learning. 'Transfer' is especially sought across the disciplines in Science, Technology, Engineering and Mathematics (STEM) education and Humanities And Social Sciences (HASS) transdisciplinary work and studies, and guidance for students to attain Transfer of cognition is needed.

If there were advantages of providing the AMERT framework as an explicit metacognitive routine that is memorable to students, the word ‘Monitor’ could be replaced by ‘Look’ so the acronym spells the more memorable ALERT:

- Aware of thinking: what thinking skills do you know about?
- Look at your thinking: what thinking skills are you using right now?
- Evaluate your thinking: what thinking skills do you need to change or keep active right now?
- Regulate your thinking: how will you change your thinking skills?
- Transfer your thinking: how will you use your thinking skills that you learned in another activity in this current activity?

Limitations and biases

This study has examined the viability of the AMERT hierarchy for metacognition with only a small sample of students from one cohort in one science degree. Confirmation bias may be present in the interview data where students may have provided the interviewer what they perceived the researcher wanted to hear, however this risk was mitigated by the lack of interview cues about metacognition. The analysis identified epitomising statements of students’ experience to provide evidence of each level of AMERT, but not what is typical. While there was evidence of the first four levels of AMERT for each facet, the evidence for hierarchy between these levels was inferred, not direct. While disconfirming evidence is absolutely necessary, interviews that do not directly ask about metacognition have little capacity to provide such evidence. Only substantial further research on AMERT, first on its viability and, if warranted, then validity and finally on the reliability of measures from instruments that it frames, will be able to confirm or disconfirm this hierarchical framework as appropriately portraying metacognitive elements and their relationships. The use of this paper’s analysis protocol by other research teams for secondary analysis of rich interview data is a way for to test the viability of AMERT efficiently. Moreover AMERT as a conceptual framework could inform systematic literature reviews of research that has published rich qualitative data such as direct quotes.

Conclusion

If facilitated metacognition can contribute to student learning gains to the extent claimed by the literature, then understanding metacognitive teaching and learning strategies should be one of the top research priorities in education. As metacognition can be a conceptual glue between diverse learning contexts for a student, metacognitive teaching and learning strategies should be particularly important in trans/disciplinary STEM and HASS education. However, the value of research on metacognitive gains is equivocal due to concerns about construct validity and instrument reliability, where current disparate measures of metacognition reflect a diversity of metacognitive frameworks. The majority of frameworks for metacognition are non-hierarchical and some are overly complex with unhelpful overlap among metacognitive elements and inclusion of elements that are not metacognitive. This paper presented a hierarchical, five-level metacognitive framework that is a synthesis of the literature from the 1970s to the present and comprises self-Aware of cognition, self-Monitor cognition, self-Evaluate cognition, self-Regulate cognition and self-Transfer cognition. The use of AMERT to analyse data from the empirical study in this paper supports the viability of the framework in one context. Further qualitative studies will need to more fully test the viability of AMERT and, if the hierarchical framework is supported by diverse qualitative studies, quantitative studies are then warranted that determine the framework's construct validity and the reliability of instruments developed from it. The development and testing of AMERT presented here is a step towards an empirically-validated and practical metacognitive framework for teachers and researchers that may help students to be metacognitively alert in science.

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Authors' contribution statements.

John Willison contributed to the study conception and design, material preparation, data collection and final manuscript preparation. Claire Draper, Laura Fornarino, Menghua Li, Tala Sabri, Yan Shi, and Xinshuo Zhao performed data analysis and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Table

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