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A Review of Metacognition: Implications for Teaching and Learning

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A Review of Metacognition: Implications for Teaching and Learning

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Abstract

This working paper reviews the literature on metacognition and suggests ways of acquiring metacognition in student learning. In Singapore, metacognition has been a key feature of the Mathematics and English Language curricula and is postulated to gain more prominence in the teaching and learning of Mathematics and English Language in the state's schools in the 2020 syllabuses. This paper locates the relevance of the concept of metacognition within the broader context of future economy and the imperative of developing in students the 21st century skills (e.g., problem-solving, critical thinking, communication and collaboration, adaptability, and digital literacy skills). Current concerns about the challenges of "future" learning and economy may be addressed by the concept of metacognition. Metacognition, according to Flavell (1979), is about "one's knowledge concerning one's own cognitive processes …" (p. 906) or simply "thinking about one's thinking"*. Helping students to become aware of themselves as learners and to take control of their learning process through concepts linked to metacognition are possible ways of preparing learning at school and beyond, and for the future. In this regard, this working paper introduces the components of metacognition and outlines the ways in which students' metacognition is measured. In meeting the challenges of the future economy that involve solving unimagined problems in new contexts or domains, this paper also discusses the importance of domain-specificity and domain-generality* *of metacognition in education, and reveals the current inconsistency which researchers have in defining the two terms. The paper concludes with a brief summary of metacognitive strategies used in four different domains—(a) language and literacy instruction; (b) learning of Mathematics; (c) learning of Science; and (d) learning of humanities subjects—which teachers can draw upon for classroom-based learning and beyond. Implications for policy, practice and future research are also discussed.*

Introduction

The purpose of this working paper is to provide an overview of metacognition and its associated concepts by reviewing the literature on metacognition and suggesting ways of acquiring metacognition. Metacognition has a central place in the Mathematics and English Language curricula in Singapore, particularly with its increasing emphasis on explicit teaching and learning in their 2020 syllabuses. This paper locates the relevance of the concept of metacognition within the broader context of future economy and the imperative of developing in students the 21st century skills (e.g., problem-solving, critical thinking, communication and collaboration, adaptability, and digital literacy skills) (OECD, 2018). Current concerns about the future economy and education, as noted by the state's Second Minister for Education, are typified by volatility and complexity (Rajah, 2018), which cannot be simply addressed with a set of run-of-the-mill prescriptive solutions. Educating students with the need for "skills, innovation, adaptability and flexibility" (Rajah, 2018, "Education for Our Future," para. 18) to navigate through the uncertainties of the future will be even more vital than before. Conceptualised as "one's knowledge concerning one's own cognitive processes …" (Flavell, 1976, 1979, p. 906) and learners' awareness and knowledge, including their abilities and tendencies to control the processes involved in learning (Derry, 1990), metacognition can be seen as a tool for helping students become self-regulated learners and achieve deep learning for the future.

Research into metacognition has widely acknowledged its two main characteristics—*knowledge* about and *regulation* of cognition (thinking) (Brown, 1978; Cross & Paris, 1988; Flavell, 1979; Paris & Winograd, 1990; Schraw, Crippen, & Hartley, 2006;

Schraw & Moshman, 1995)—and their integral role in acquiring deep and meaningful learning (Akyol & Garrison, 2011; Brown, Bransford, Ferrara, & Campione, 1983; Garrison & Akyol, 2015) which necessitates learning to be transferred in one way or another. What is possibly needed *in* and *for* the future economy is the ability to apply knowledge and skills acquired from different domains to unimagined problems in new contexts (OECD, 2018). Cultivating metacognitive strategies, particularly those directed for transfer, would hopefully allow students to make deliberate and explicit connections to their learning across contexts, and between current and future learning.

Metacognition is also regarded as a valuable predictor of learning in the education community (Veenman, Wilhelm, & Beishuizen, 2004). Veenman, Van Hout-Wolters, and Afflerbach (2006) noted from their study that intellectual ability, on average, uniquely accounts for 10% of the variance in learning whereas metacognitive skills account for 17% of the variance in learning. Both predictors share another 20% of variance in learning for students of different ages and background, different types of tasks, and different domains. Such findings suggest that an adequate level of metacognition may compensate for students' cognitive limitations (Veenman et al., 2006).

Metacognitive training and instruction have also shown to have positive effects on students' performance in Mathematics, problem-solving and reading (Zohar & Barzilai, 2013). In fact, teaching approaches that place emphasis on students' metacognitive and self-regulated learning are credited as the most effective approaches for enhancing pedagogical practices (Hattie, 2008). For this reason, this paper will examine what metacognition can do for students' learning. Specifically, this paper will look at the (1) metacognition and its components; (2) measurement of metacognition; (3) domain-generality and domain-specificity of metacognition; (4) ways in which schools and teachers can facilitate students' development and acquisition of metacognition; and (5) research in teachers' metacognition. This paper will conclude with some recommendations on how metacognition and metacognition instruction can be better enacted in educational settings for policy, practice and future research.

Metacognition, Components and Related Constructs

Historical development

By outlining the early history and the conceptual developments of metacognition and its components, claims on the applications and uses of metacognitive strategies in today's context can be better understood and thus appreciated. In 1973, Flavell coined the term "metamemory" to describe young children's beginning awareness about memories and how to remember (Flavell & Wellman, 1975, 1977). In the early 70s, Ann Brown and others emphasised how children learn to control cognitive and behavioural actions to foster remembering (Brown, 1973; Brown & Campione, 1972). Flavell wrote his first paper on metacognition that emphasised knowledge about memories in 1976 and Ann Brown wrote hers on metacognition that focused on monitoring what one knows and does not know (including inconsistencies in knowledge), and improving remembering activities and strategies (Brown, 1975; Flavell, 1976). Flavell was interested in memory development and Brown pushed metacognition into the educational realm her interest in mental retardation and educational remediation. This was later expanded into reading comprehension and education (Brown, 1982). Brown continued her commitment to educational research and likewise her focus on metacognition and cognitive control of learning processes. Memory researchers, including Borkowski and Pressley (Cross & Paris, 1988; Pressley, 2002; Pressley, Borkowski, & O'Sullivan, 1985) advanced Brown's ideas into reading and education. Myers and Paris (1978) conducted one of the earliest empirical studies on metacognition about reading and Paris, Lipson, and Wixson's (1983) paper on "Becoming a strategic reader" was one of the earlier ones to chart the developmental aspects of metacognition and cognitive control in reading. Subsequent research on memory, metacognition and motivation led to research on self-regulated learning.

Metacognition and its components

Metacognition refers to "one's knowledge about one's own cognitive processes or anything related to them" (Flavell, 1979, p. 906). The term was later expanded by researchers in the field to include *awareness and management of one's own thought* to reflect metacognition as a form of executive control, involving monitoring and self-regulation (Cross & Paris, 1988; Kuhn & Dean, 2004; McLeod, 1997; Paris &

Cross, 1983; Schneider & Lockl, 2002). Defining metacognition is not straightforward due to the range of terminologies used, such as self-regulation, metamemory and executive control. It is challenging to define them clearly since each term implicates different cognitive processes and is involved in complex relationships (e.g. planning, evaluating) during a cognitive task. While there are slight differences between the definitions of the aforementioned terms (Zile-Tamsen & Marie, 1996), all terms emphasise the executive role of metacognition as a higher-order thinking skill that ensures one is capable of planning, monitoring and regulating the cognitive processes. It is in this sense that metacognition has its relevance in the educational context, particularly in promoting the analytical and critical thinking skills. Accordingly, this has given rise to metacognition comprising three components: (1) metacognitive knowledge (Kreutzer, Leonard, Flavell, & Hagen, 1975); (2) metacognitive control and regulation (Pintrich, Wolters, & Baxter, 2000); and (3) metacognitive experiences (Flavell, 1979).

In essence, it is more widely accepted in the field of cognitive psychology that metacognition comprises two components: knowledge about cognition and regulation about cognition (Cross & Paris, 1988; Flavell, 1979; McCombs, 1998; Paris & Winograd, 1990; Schraw et al., 2006; Schraw & Moshman, 1995). Cognitive knowledge includes understanding about the self as a learner (declarative knowledge) and the awareness and effective application of cognitive strategies (procedural knowledge) (Cross & Paris, 1988; Paris et al., 1983; Schraw et al., 2006). Paris et al. (1983) further distinguished a different knowledge; why and when to use a particular strategy (conditional knowledge). Cognitive knowledge focuses on the interactions between the person, task, and strategy (Flavell & Wellman, 1977). The other component of metacognition is cognitive regulation which encompasses activities such as planning, monitoring and evaluating (Cross & Paris, 1988; Paris & Winograd, 1990; Schraw et al., 2006; Schraw & Moshman, 1995) that may give rise to a conscious cognitive experiences (Flavell, 1979; Kreutzer et al., 1975). An example of cognitive experiences would be a person asking himself whether he has understood what he is reading. Here, cognitive experiences serve to check one’s progress towards achieving a goal (Flavell, 1981; Pressley et al., 1985; Wellman, 1992).

The term "metacognitive experiences" is less commonly used although Flavell (1979) and Wellman (1992) studied children's "feelings of knowing" in memory development as precursors to emerging knowledge and as an early part of Wellman's research on common sense Theory of Mind on young children. In recent decades, the importance of metacognitive experiences has been foregrounded in students' learning (Efklides, 2001, 2006). Metacognitive experiences comprise feelings, judgements and task-specific knowledge, and examine the affective aspect of metacognition. This component has been relatively under-researched and could be an important facet for researchers who are using the neuropsychological measures. Broadly speaking, the three components that make up metacognition, according to Efklides (2006), are metacognitive knowledge, metacognitive experiences and metacognitive skills (see Table 1).

Table 1. *Monitoring and control*

Monitoring		Control
Metacognitive Knowledge	*Metacognitive Experiences*	*Metacognitive Skills*
• Ideas and beliefs of - Person/self - Task - Strategies - Goals - Cognitive functions - Validity of knowledge - Theory of mind	• Feelings of familiarity, difficulty, knowing, confidence, satisfaction • Judgement of learning, memory, information • Estimate of effort, time • Online task-specific knowledge, task features, procedures employed	• Conscious, deliberate use of strategies for effort, time, monitoring, planning, regulation of cognitive processing, evaluation of outcome

Adapted from (Efklides, 2006)

The initial studies of metacognition, as outlined earlier, revealed an understanding of how thinking encompasses a set of skills beyond information that is accessible for learning. With the growing interest in educational research in metacognition in the past decade, concerns about the overly simplistic understanding of the multidimensional concept of metacognition that is often taken up in teaching and learning have emerged. The conceptual "fuzziness" surrounding the executive functioning of metacognition has been noted by Tarricone (2011). Irregularity of metacognition as a concept was also observed by Bannister-Tyrrell, Smith, Merrotsy, and Cornish (2014). In view of this, Tarricone's (2011) taxonomy and conceptual framework of metacognition offered as a more accessible scaffold, keeping in mind its comprehensiveness (Bannister-Tyrrell et al., 2014) which included the interconnectedness of the different aspects of Tarricone's framework and the significance of this to how they underlie the metacognition and the epistemological beliefs of a student to facilitate or inhibit learning (see below subsection on metacognition and beliefs). Tarricone's taxonomy of metacognition, including its supercategories, and subcategories are summarised in Figure 1 (see below).

Metacognition and self-regulated learning

Self-regulated learning theorists argue that metacognition is a key aspect of self-regulated learning (Pintrich & De Groot, 1990). Individuals can be described as self-regulated when they are active participants in their own learning process (Zimmerman, 1989). This perspective of self-regulated learning subsumes the notion of metacognition under self-regulated learning. A self-regulated learner uses specific strategies, (e.g., organising and transforming information

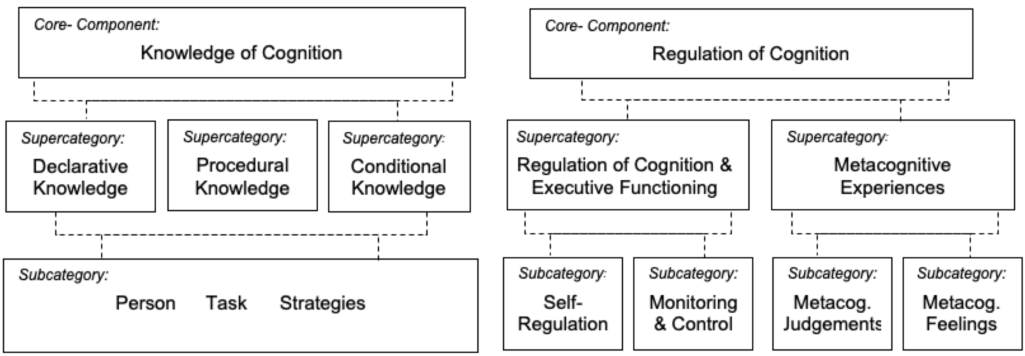

Figure 1. *Adaptation of Tarricone's Subcomponents, Categories, Supercategories, Subcategories and Key.*

Elements of Metacognition (Bannister-Tyrrell, Smith, Merrotsy, & Cornish, 2014) according to its context of use, seeking information and rehearsing or using memory aids) which are metacognitive in nature, to achieve his or her learning goals on the basis of self-efficacy perceptions (Paris & Byrnes, 1989). Self-regulated learners are also better aware of their knowledge, beliefs, motivation and cognitive process, and are thus able to adjust strategies to meet their goals and make progress (Butler & Winne, 1995; Cleary & Zimmerman, 2012). The process of self-regulation is often viewed as the motivational equivalent of metacognition (Prawat, 1998; Zimmerman, 2008). However, it is beyond the scope of this paper to further elaborate on the topic of self-regulation. See the above cited references in this subsection for further details.

Metacognition and motivation

Another construct that is closely linked to both metacognition and self-regulated learning is motivation. Often, learners need the motivational vigour to direct their thought processes (whether in a cognitive or metacognitive manner) and actions (i.e., behaviours) towards the completion of a learning task (Dweck & Bempechat, 1983; Elliott & Dweck, 1988). Learners also need to understand and believe that effort is required to apply strategies, and that effort would often produce results and success (Pintrich, 1989). This attributional belief is the energising factor that motivates students and learners to take on learning challenges without undue fear of failure (Borkowski, Johnston, & Reid, 1987; Covington, 1983; Nicholls, 1983). As Borkowski, Chan and Muthukrishna (2000) note, long-term changes in such behaviours are likely to depend on the interplay of factors involving learners' understanding of the specific strategy knowledge, self-regulation and motivational beliefs. Again, just like the above subsection on self-regulated learning, motivation is another specialised area in the field of teaching and learning which warrants its own literature. See the above cited references in this subsection for further discussions.

Metacognition and beliefs

Motivation serves more functions than solely to energise or direct behaviour. There is an apparent connection between beliefs such as perceptions of self-efficacy, self-competence and effort, and thinking about *self* (Harter, 1999). For instance, one might think about his/her own thinking (in terms of metacognitive knowledge, regulation and experiences) and conclude that s/he is incapable of learning how to do a certain task, or that this certain task will require more effort than what s/he is willing to put in, or that if s/he tries hard to complete the task and s/he fails, it would be a reflection of his/her lack of ability. These ideas can become personal beliefs that have huge effects on students' effort and persistence. Metacognition and motivation can be mediated by ideas of self-perceptions and beliefs because they are all mental evaluations of self, task and strategies (Flavell, 1979).

Hofer and Pintrich (1997) explored the "epistemological beliefs" as the connection between metacognition and motivation. Students' behaviours are likely to depend on their understanding of the interplay between specific strategy knowledge, self-regulation and motivational beliefs. Paris (2002) examined how beliefs about person, task and strategies could influence how students act appropriately or inappropriately. He posits that there are positive (e.g., determination and grit) and negative outcomes (e.g., low self-esteem, low self-worth, shame and drop out) that might arise from embracing metacognition, adopting motivational beliefs and self-perceptions that influence learners' behaviours. Additionally, Paris (2002) explored cases of orientations of metacognitions and beliefs, and further argued that there could be "good" (as in more productive) and "bad" (as in unproductive) metacognition that would affect the kind of strategies for their learning. For instance, if a student believes that s/he is just not good in a certain subject and there is no way s/he is going to get an acceptable grade, the student will unlikely put in any effort or activate any learning tactics or strategies even if s/he is fully aware and know how to use them. Here, the context of a result-driven school culture may be translated into the classroom context, further perpetuating the belief of being unable to excel regardless of one's metacognitive knowledge and skills. Thus, the role of ensuring a conducive and supportive learning culture to explore and learn metacognitive strategies, instead of relying solely on the techniques of teaching of metacognition in classrooms, is imperative. On the other extreme spectrum of beliefs where one holds unrelated or irrational behaviours; one might choose to study by putting a book under one's bed and hoping for some "diffusion" or "osmosis" to take place, or one might blame someone for casting a spell on him/her to fail in an examination.

The relations between epistemological beliefs and metacognition are complex and are specialised fields of studies (Tarricone, 2011). Although it is not within the scope of this paper to delve into the details, we would like to suggest to readers the works cited above for further insights.

Measurement of Students' Metacognition

There are two factors to consider in measuring students' metacognition: (1) when (e.g., whether students' metacognition is to be measured before [prospectively], during [concurrently] or after [retrospectively] students have engaged in a task); and (2) how (e.g., whether to use self-reported questionnaires or interviews with participants).

When and what to measure

Metacognition can be measured either concurrently, retrospectively or prospectively. "Concurrent" methods are also known as "online" measures that attempt to examine students' metacognition while they are working on a task (Efklides, 2006; Gascoine, Higgins, & Wall, 2017; Veenman et al., 2006). Concurrent protocols allow access to the contents of working memory without having to rely on students' long-term memory. Retrospective or prospective (or "offline") metacognitive measurements evaluate students' metacognition before or after the activity has occurred. Self-reported questionnaires, surveys and tests are typically retrospective or prospective measures. Interview and task-based methods are usually more concurrent in nature.

The "when" factor (i.e., whether concurrent, retrospective or prospective) is not contentious because students and learners can be queried about their thoughts and actions before, during and after a task. The more critical factor is "what" to measure. For the past 40 years, researchers have only endeavoured to define and measure metacognition that are presumed to be useful, such as study strategies and time management (Paris, 2002). The definition of what to measure consequently impacts the "how" factor. For instance, the assessment of experiences and unconscious knowledge have proven to be difficult or even impossible. However, in light of the above discussion on negative beliefs (the above subsection on metacognition and beliefs), the accuracy of delineating metacognition is not the real issue. The more fundamental issue is whether a person acts according to one's beliefs (Harter, 1999; Paris, 2002). For instance, if someone believes that one is worthless because one has failed a course and as a result did something foolish, then it can be said that the person was acting upon his/her beliefs. The most important feature of metacognition is whether how it influences one's thoughts and actions, not whether it is true or accurate. If the person instead of advocating his/her failure and therefore giving up on trying harder but enrols in a tuition class, it means that s/he is acting upon his/her beliefs in a positive manner. It would be more beneficial to connect metacognition to interventions that could promote emotional well-being and positive thinking and subsequently, positive actions.

How are students' metacognition measured?

In a systematic review of the methods on measuring or assessing metacognition in children aged 4 to 16 years, over a 20-year period from 1992 to 2012, Gascoine et al. (2017) identified the following six categories of measurement for students' metacognition. As a point to note, each tool or method does not always exclusively fit into just one category (Gascoine et al., 2017) and each method has its own pros and cons; there is no one best method.

Self-reported questionnaires, surveys, and tests

Self-reported questionnaires/surveys such as Likert scale typically elicit participants' perceptive responses. Tests are administered to assess knowledge and skills in specific domains, usually coupled with self-reported questionnaires/surveys to ascertain students' levels of metacognition. Self-report survey questionnaires are relatively cheap and easy to implement but are open to self-serving bias and distortion.

Observation-based methods

For *observation-based methods,* students' metacognition awareness levels are observed. This method may also be facilitated by video recordings and coded based on a framework or certain phenomena such as students' attention to instructions, seeking help, monitoring progress, involvement in class, metacognitive talk, metacognitive knowledge, metacognitive regulation and, emotional and motivational regulation. Observations could be done concurrently (e.g., students in classroom) or retrospectively, aided by technological means (e.g., video clips). However, the observed behaviour is subjected to interpretation by observers and coders. In addition, observation of participants' overt behaviour disregards their thought processes, be it cognitive or metacognitive.

Teacher ratings

In this method, teachers rate students' level of metacognition against a scale or an instrument instead of students' self-report. For instance, teachers rate students on a scale of 1 to 6, based on behavioural descriptors. Although teachers have more interactions with their own students than external observers, this method suffers similar shortcomings as those of the observation-based methods.

Interviews and focus groups

For *interviews and focus groups*, students are interviewed to assess their levels of metacognition against a set of rubrics or interview questions. Typically, students are asked questions on their metacognitive experiences—cognition and regulation of cognition such as planning, monitoring and checking. Interviews and focus groups offer a form of triangulation but suffer from similar issues associated with self-report survey questionnaire. As interviews and focus groups are "self-report" in nature, they are also open to self-serving bias and distortion, as in the case of the survey questionnaires.

Task-based methods and tests

Students' metacognition is measured through their participation in tasks like completing computer-based tasks, drawing concept maps or solving problems. The task-based methods and tests are more product- than process-oriented. That is, it is the final products or scores that will be assessed. While these methods are less resource intensive in terms of time and manpower requirements, they do not allow for understanding of the mental processes of the participants. The problem with the product is that it may not reveal much information for understanding of the mental process of participants, unless accompanied with questions to elicit students' explanation on how they solve the task.

Multi-method tools

The *multi-method approach*, as the name implies, uses a mixture of the methods mentioned above. As there is no one best way to assess students' metacognition, some research studies used the multi-method approach. As there are issues with each of the methods mentioned above, a multi-method approach could compensate for the shortcomings of a single method. However, this does not totally eradicate all the problematic issues associated with measuring and assessing students' metacognition.

Please refer to the appendix section of this working paper for the various types of measurements (e.g., self-report survey questionnaires, observations, verbal reports and interviews, and task-based assessments—see Appendices A to E) that are discussed in greater detail for a better understanding of the different instruments and more importantly to have an in-depth appreciation of how the concepts of metacognition and regulation of learning are being operationalised into more behavioural terms. A subsection on the instrument for measuring teachers' metacognition is also included (see Appendix F).

Domain-Generality or Domain-Specificity

A number of studies have looked into the issue of whether metacognition is domain-specific or domain-general but such studies have yet to provide conclusive results to date (Jiang, Ma, & Gao, 2016).

Domain-generality

Many have argued that metacognition is a domain-general process (Schraw, 1998; Schraw, Dunkle, Bendixen, & Roedel, 1995; Veenman, Elshout, & Meijer, 1997; Veenman et al., 2004). In a study conducted by Veenman and Verheij (2003), they attempted to determine whether metacognitive skilfulness was entirely part of intelligence and whether it was a predictor of learning. The study involved 16 university students participating in an experiment where they were asked to perform two tasks (one of the tasks was part of their curriculum while the other was an unfamiliar discovery learning task) while thinking aloud. The participants' metacognitive skilfulness and learning performance were then assessed. Their examination grades and academic performance were also collected for analysis. The findings showed that metacognitive skilfulness in part contributed to learning results and is independent of intellectual ability hence suggesting the domain-generality of metacognition. Such findings point to the domain-generality of metacognitive knowledge hence reinforcing Schraw's (1998) claim that metacognition is domain-general in nature.

In addition, based on an elaborate instance of a theoretical analysis of meta-strategic knowledge (MSK), Zohar and David (2009) were able to further extrapolate a general model for conceptual analyses of other components of metacognition. The method in which extrapolation was conducted is as follows: define the sub-component followed by examining the sub-component in relation to a) general conceptual metacognitive issues highlighted by leading theorists; b) empirical finding pertaining to the sub-component; and c) definition formulated and problems presented by other researchers who tackled the corresponding sub-component. Concomitantly, the way in which MSK is defined adopts a more domain-general approach and is closely associated with the Procedural Meta-Knowing as presented by Kuhn (1999, 2000, 2001a, 2001b). The learner with high MSK is able to articulate his or her understanding of the task and possible strategies to be applied for subject-based task. Furthermore, empirical findings indicate learners possess a substantial degree of domain-general knowledge thus enabling them to transfer MSK from current and pre-existing understanding to new learning contexts and subjects (Zohar & David, 2009). Knowledge transfer between disciplines is in fact the general element in knowledge; it is shared among several specific domains. MSK contributes to the understanding that metacognition includes higher-order thinking, and it is a subdivision of metacognitive monitoring, comprising knowledge of tasks and strategies.

Domain-specificity

Scott and Berman (2013) defined metacognition as students' knowledge and regulation of cognition and their accuracy in predicting their academic performance. The quantitative findings from their research study suggested that metacognitive knowledge and regulation are domain-general while metacognitive accuracy was domain-specific.

In a study conducted by Neuenhaus, Artelt, Lingel, and Schneider (2011) that examined the structure of metacognitive knowledge in Grade 5 students and its relation to their school achievements, the authors noted that although their findings suggested some degree of domain specificity, they also revealed a strong relationship between general metacognitive knowledge and domain-specific knowledge.

As reported in another study, to improve reasoning amongst learners, explicit intervention through metacognitive scaffolding, reflection and generalisation in content-specific education is required for learners to be engaged in problem-solving, understanding and applying abstract concepts (White & Frederiksen, 1998). Drawing on the cognitive model *ThinkerTools* and corroborative learning, learners would then anchor domain-specific metacognitive knowledge, specifically in the domain of scientific reasoning. The study found that despite learning domain-specific metacognitive strategies, students reported that the Inquiry Cycle and Reflective-Assessment Processes in ThinkerTools are transferable to other subject-domains such as English Language, History and Mathematics (White & Frederiksen, 1998).

Functions of domain-generality and domain-specificity

From the above discussion and due to differing views, whether metacognition is domain-specific or domain-general may still require further deliberations. We acknowledge that metacognition could be both domain-general and domain-specific. In our view, domain-general metacognition would be of greater interest in the educational context as it relates to the transfer of learning (Pintrich, 2002), involving the ability to use knowledge gained in one context, setting or situation in another (Bransford, Brown, & Cocking, 2000). Students who possess awareness of the various kinds of strategies for thinking, learning and problem-solving are more inclined to use them at their disposal. Furthermore, the integration of general/generic metacognitive strategies with subject-specific learning could have increased student achievement and aid independent student learning (Bransford et al., 2000). One of their key findings that supports constructivism and inductive methods is that "all new learning includes transfer of information grounded on previous learning" (p. 53). Therefore, instead of treating subjects or new topics as independent units or with little reference to pre-existing concepts, learners will be able to grasps new knowledge better when drawing on pre-existing knowledge, if the new content is fully consistent or has general-domain elements that can be mapped across. What distinguishes transfer of learning from mere retention of knowledge is sense-making and understanding of the knowledge of what students have learnt.

Schraw (1998) observed that while cognitive skills tend to be subsumed under domains or subject areas, metacognitive skills span multiple domains although such domains have little in common. It is also expected that metacognitive knowledge and regulation will improve as one gains more understanding and knowledge in a particular domain. That is, as students acquire more metacognitive knowledge in a number of domains, they may be able to construct general metacognitive knowledge (e.g., understanding one's memory capacity) and regulatory skills (e.g., using appropriate learning strategies) that cut across all academic domains (Schraw, 1998). This is particularly true for older students who not only acquire more knowledge but tend to be also more versatile in their thinking. Borkowski et al. (2000) and Neuenhaus et al. (2011) also argued that the development of metacognitive knowledge begins as highly domain- and situation-specific and becomes more flexible and domain-transcending or general with practice and experience.

Hence, while metacognitive activities that learners engaged with may seem different across disciplines such as reading, solving mathematical problems or tackling a Physics question, these seemingly different activities stem from parallel metacognitive grounds (Veenman, 2012). That is, specific overt activities, evoked by different learning tasks, spring from a similar metacognitive base. For instance, if you have the same person performing a reading task and a problem-solving task, in both instances, that person's orientation, planning and other metacognitive activities and processes internally enlisted are common even though they may look different outwardly. There is ample evidence that metacognitive activities or metacognitive skills are domain-general by nature rather than domain-specific (Morales, Lau, & Fleming, 2018; Veenman et al., 1997; Veenman & Verheij, 2003). However, metacognitive accuracy tends to be used in the domain-specific sense (Scott & Berman, 2013). Clearly, students have a personal repertoire of metacognitive skills and strategies that they apply whenever they encounter a new learning task. This notion of general metacognitive skills has implications for training and transfer of those skills across tasks and domains (Veenman, 2012; Veenman et al., 2006), particularly in learning at schools.

Promoting Metacognitive Awareness

The importance of developing metacognitive knowledge for educational contexts was first highlighted in the field of memory development (Pressley, Borkowski, & O'Sullivan, 1984). Specifically, findings from studies that focused on children's strategy development indicated that education and practice, rather than age, played an integral role in most memory and metamemory development (Kail & Hagen, 1977; Kreutzer et al., 1975; Ornstein, 1978). Apart from understanding the definitions of metacognition, how to measure it and the issues of domain-specificity or domain-generality, the question of how to promote or facilitate the acquisition and learning of metacognition are of utmost importance to the teaching community (Brown, 1975, 1978).

A number of metacognition proponents suggest ways and strategies to promote students' metacognition. A number of them suggest generic approaches and strategies (Ellis, Denton, & Bond, 2014; Jones & Idol, 1990; Pintrich, 2002; Schraw, 1998) while others propose more specific tactics in the teaching of reading and listening comprehension (Goh, 2018; Paris & Winograd, 1990), Mathematics problem-solving (Lee, Chang, & Lee, 2001; Lee, Yeo, & Hong, 2014; Pólya, 2004), humanities subjects, namely Geography, History and Social Studies (Aydin, 2011; Bean, Singer, Sorter, & Frazee, 1986; Brickell & Herrington, 2006; Ciullo & Dimino, 2017; Hooghuis, van der Schee, van der Velde, Imants, & Volman, 2014; Kriewaldt, 2006; Roberts et al., 2014), and Science inquiry (Schraw et al., 2006; Zohar & Barzilai, 2013).

Generic approaches to promote metacognition among students

Schraw (1998), citing Hartman and Sternberg (1992), suggests four general approaches to increase metacognition for teaching and learning in schools. They are: (1) promoting the general awareness of metacognition; (2) improving knowledge of metacognition; (3) improving regulation of cognition: and (4) fostering environments that promote metacognitive awareness.

Promoting general awareness

Teachers need to provide opportunities for students to heighten their metacognitive thinking, that is, to understand the difference between cognition and metacognition, and thereby become more self-regulated learners (Schraw, 1998). This can be achieved with practice and reflection over a period of time and it would be best done from a whole-school approach. First, teachers need to take time to discuss and talk about the importance of metacognitive knowledge and regulation (i.e., the special role they both play in self-regulated learning). Second, teachers should make a collective effort to model their metacognition, in particular, what and how they think about a concept or when answering questions and monitor their own performance (Schraw & Dennison, 1994). Often, teachers tend to demonstrate how they solve a question instead of describing or thinking aloud their thought processes on how to solve the question. Third, teachers should allocate time for group discussion and reflection amidst their tight and hectic curriculum.

Improving knowledge of cognition

Derry (1990) argued that the development of general thinking capacities and higher-order thinking require basic curricular knowledge to be learnt in a way that is meaningful and relevant for future problem-solving. For Derry, higher-processing abilities build on the prerequisite learning of certain core skills and subskills. Hence, learning strategies could be used to facilitate the learning of declarative (facts and concepts) and procedural (how) knowledge. While different courses often emphasise the importance of one particular knowledge form over the other, expertise in most subject-matter domains requires access to the learning of both declarative knowledge and procedural skills. Table 2

Table 2. *Learning tactics.*

Declarative Knowledge	Procedural Knowledge
a. Simple attention focusing, such as highlighting and underlining b. Structured focusing, such as looking for headings c. Schema building, such as story grammar and schema training (e.g., generalisation, enumeration, sequence, classification and compare/contrast) d. Elaboration techniques, such as self-questioning, imaging and analogies	a. Hypothesising b. Seeking reasons for actions c. Using examples and non-examples d. Algorithms e. Reflective self-instruction f. Part practice (e.g., drills on one specific aspect of performance) g. Whole practice (i.e., student practises full performance)

Adapted from Derry (1990)

shows the learning tactics that can be used as strategies for acquiring declarative knowledge and procedural knowledge.

Following closely, Schraw (1998) suggested the use of instructional aid such as the strategy evaluation matrix (see Table 3). The matrix consists of five strategies with simple suggestions and questions on how, when and why to use specific strategies like skimming or activating prior knowledge. Students can be instructed to follow the matrix individually or as a group to practise each of the strategies over a period of time. For instance, a student can focus on using each of the strategies listed over a month and more strategies over the year to gain mastery of them. Continuous practice of the strategies with reflection and discussion with the teacher and classmates is essential to achieve the effectiveness of using the strategies. According to Schraw (1998), teachers who used the matrix found it useful in promoting students' cognitive skills, metacognitive awareness and construction of knowledge about how, when and where to use the strategies.

Improving regulation of cognition

Schraw (1998) also suggested using the regulatory checklist to complement the strategy evaluation matrix. The checklist, as shown in Table 4, provides explicit prompts to help students be more strategic and systematic in their problem-solving encounters. Teachers could

Table 3. *Strategy evaluation matrix.*

Strategy	**How to Use**	**When to Use**	**Why to Use**
Skim	Search for headings, highlighted words, previews, summaries	Prior to reading an extended text	Provides conceptual overview, helps to focus one's attention
Slow down	Stop, read and think about information	When information seems especially important	Enhances focus of one's attention
Activate prior knowledge	Pause and think about what you already know. Ask what you don't know.	Prior to reading or attempting an unfamiliar task	Makes new information easier to learn and remember
Mental integration of knowledge (prior and new)	Pause and think about what you already know. Question what you don't know. Try to relate what you don't know to what you already know. E.g. relating to the main ideas. Use these to construct a theme or conclusion.	When encountering an unfamiliar task or learning complex information or when a deeper understanding of a certain concept is needed.	Reduces memory load by making new information easier to learn and remember.
Strengthens one's understanding of prior knowledge and promotes deeper level of understanding.			
Diagrams	Identify main ideas, connect them, list supporting details under main ideas, and connect supporting details.	When there is a lot of interrelated factual info	Helps identify main ideas, organise them into categories. Reduces memory load.

Adapted from Schraw (1998)

Table 4. *Regulatory checklist.*

Type of questions	Planning	Monitoring	Evaluating
Goal-related	1. What is my goal?	1. Am I reaching my goals?	1. Have I reached my goal?
Strategies-related	1. What kind of information and strategies do I need? 2. How much time and resources will I need?	1. Do I need to make changes? 2. Do I have a clear understanding of what I am doing?	1. What worked? 2. What didn't work? 3. Would I do things differently next time?
Task-related	1. What is the nature of the task?	1. Does the task make sense?	---

Adapted from Schraw (1998)

explicitly explain and discuss with students how to plan, monitor, and evaluate their own learning. These strategies are generic and can be used for a wide range of subject domains.

Fostering conducive environments

Metacognitive knowledge and skills are often influenced by contextual and social factors. In some cases, students may be equipped with the necessary metacognitive skills and knowledge but do not use them at all or effectively. If they do use them, students might not attribute their success to these skills and knowledge. In addition, the level of effort put in by the students may be mediated by their level of motivation. In the above section on metacognition and beliefs/motivation, Hofer and Pintrich (1997) highlighted the link between students' or learners' beliefs and motivation. Students may not want to put in the extra effort (i.e., lack motivation) when they perceive a low chance of success. Schraw (1998) suggests that classrooms should facilitate mastery of goal orientation to focus on increasing students' level of performance and rewarding increased effort and persistence. This is one way to foster a conducive environment to increase metacognition for learning in classrooms.

Metacognition in language and literacy instruction

In research on language learning strategies, both descriptive and instructional, there is evidence that language learners engage in metacognitive knowledge and processes (Chamot, 2005). Chamot (2005) observed that young children in language immersion classrooms often describe their own thinking processes and demonstrate metalinguistic awareness. There is much consensus that metacognitive strategies can and should be taught explicitly to enhance language learning. In literacy instruction, Paris and Winograd (1990) identified four approaches that draw on metacognition. They are: (1) direct instruction; (2) scaffolded instruction; (3) cognitive coaching; and (4) cooperative learning. These approaches are not mutually exclusive and may at times overlap each other.

The most efficient way is to provide direct instructions to our students. Second, scaffolded instruction focuses on the dialogue between teacher and student, with the purpose of providing adequate guidance for students to achieve learning goals that are beyond unassisted efforts. Strategies like predicting, questioning, clarifying and summarising are employed to monitor reading comprehension, for instance. As a form of expert scaffolding, reciprocal teaching (Brown & Palincsar, 1985) involves continuous trial and error from the student and continuous adjustment by the teacher to the students' current competence. In reciprocal teaching, students respond when it is their turn to be the "teacher", or when they answer the questions of other "teachers". Responses by students would allow the teacher to gauge the former's competence. According to Brown and Palincsar (1985), the teacher's role is to model the activities and engage the students at a level within their grasp. Through interactions with the supportive teacher and their more knowledgeable peers, the students are guided to perform at increasingly more mature levels. The teacher would gradually diminish his/her turn as the students take charge of their own learning. Third, cognitive coaching may incorporate elements of direct and scaffolded instruction. The common goals in coaching situations are provisions of cooperation and mutual striving, ongoing assessment of students' levels of achievements (so that learning could be adjusted accordingly), and mutual regulation where a teacher can better understand students' misconceptions through the reciprocity of the relationship. Fourth, cooperative learning involves sharing of knowledge and learning through social exchanges between students facilitated by the teacher. This form of learning involves students working together to complete a given task. Students may be more motivated to learn since they help or are being helped by fellow classmates in completing the task.

The following sections illustrate how metacognitive strategies can be used in language and literacy instruction, specifically in reading comprehension, writing instruction, and listening comprehension.

Reading Comprehension

Paris and Winograd (1990) identified three ways that influence how students read strategically: (a) existence of relevant strategies, impact of task characteristics, and students' own personal abilities (declarative knowledge); (b) execution of various actions and how to monitor and regulate comprehension (procedural knowledge); and (c) when and why to apply various strategies and knowledge (conditional knowledge). It is also observed that skilled readers know how to decode meaning from text at both letter and word levels (Pressley, 2002). Skilled readers recognise words that they need to read quite effortlessly and are likely to read actively by relating to prior knowledge, predicting the upcoming text and relating ideas read to their prior knowledge (Pressley, 2002). The seasoned reader also frequently asks questions while reading, constructs images of the ideas being conveyed in the text, summarises what is being read, is alert of specific parts of the text that interfere with reading comprehension and has the necessary strategies to react (e.g., re-reading) to such possibilities. Given such strategies a learner uses, reading comprehension skills need to be explicitly taught and discussed by the teacher with students. The teachers can explain and model the strategies, which will then be scaffolded to the students during the reading process (Pressley, 2002). Pressley (1986) developed the *Good Strategy User Model* to describe and explain how self-regulated thinking can be efficiently carried out.

The Good Strategy User Model is characterised by the prevalent use of (a) strategies; (b) specific strategy knowledge; (c) general meta-strategic knowledge and general strategies; (d) knowledge base; and (e) coordination of strategies and knowledge (Pressley, 1986; Pressley, Borkowski, & Schneider, 1987, 1989). Good strategy users (GSUs) adopt cognitive styles that support efficient thinking, which allows effective operation of other components of good strategy use (Pressley et al., 1989). Pressley, Borkowski and Schneider (1989) observed that GSUs have repertoires of memory, comprehension, composition and problem-solving skills. They also possess essential metacognitive knowledge for implementing strategies, such as knowing when and where each strategy may be useful and the amount of cognitive effort needed for using a particular strategy. For GSUs, factors such as perseverance, innate ability or task difficulty are less vital than being strategic, since performance can be improved by applying the most compatible procedures to meet the learning challenges. Strategic actions therefore require deliberate effort, online monitoring and potential revision (Borkowski, Carr, Rellinger, & Pressley, 1990). An account of good strategies for reading comprehension, writing or problem-solving is summarised in Appendix G.

Writing Instruction

As a language skill, writing provides a means of assessing not only students' linguistic abilities but also their ability to understand, analyse and construct coherent knowledge. Studies have shown that when writers reflect on their writing activities, the quality of their written products improve (Graham, Harris, & Mason, 2005; MacArthur, Graham, Schwartz, & Schafer, 1995). Baker (2011) observed that across all age groups, differences in students' conceptions of writing, knowledge of writing process and abilities to use writing strategies effectively are apparent. For instance, skilled writers are more likely to display higher-order awareness of writing process such as clarity, organisation and audience sensitivity whereas less skilled writers tend to focus on lower-order processes or the mechanics of writing like spelling, grammar and punctuation. Escorcia, Passerault, Ros and Pylouster (2017) note that experts are more likely to have global goals for their writing that consider the communicative purpose of the task and holistic revision. By contrast, novice writers rarely have overall plans for their writing and their revisions typically remain at the sentence level.

Writing has long been seen as an activity that draws on both cognitive and metacognitive processes (Hayes, 2012; Hayes & Flower, 1986). Escorcia et al. (2017) considered writing a problem-solving task involving metacognitive control of planning, text generation, and reviewing. Hayes (2012) viewed the metacognitive control of writing as an approach for coordinating both knowledge and strategies to meet the specific objectives and constraints of the writing task. For instance, a writing assignment has a specific goal to address (often signalled by the essay prompt), but it also has a particular word length that writers need to fulfil. Writing that is constructed this way places emphasis on the importance of self-regulation in writing (Kellogg, 2008) and requires writing strategies to be redefined and constantly readjusted during a given activity (Zimmerman & Risemberg, 1997).

Interest in metacognitive control of writing coincided with the development of the cognitive process model of writing by Linda Flower and John Hayes in the early 1980s. The process model of writing comprises three recursive processes: planning, translating (sentence generation), and revising. Of the three processes, planning plays an integral role in learning to write (Graham & Harris, 2005) and in skilled writing (Graham et al., 2005). While skilled writers spend a considerable amount of time planning their compositions (Hayes & Flower, 1986), struggling writers tend to play down on planning when writing (Graham, 1990; McCutchen, 1988). Indeed, writing researchers like Graham and Harris (2005) have foregrounded the role of planning as a critical area of investigation in a program of research conducted by the Center on Accelerating Student Learning in search of effective instructional practices for struggling writers in primary grades in the United States. Graham et al. (2005) demonstrated how the instructional model, Self-regulated Strategy-Development (SRSD), together with peer support, can help young students (third grade) who have difficulties with writing develop better learning strategies and knowledge for planning and composing more comprehensive and longer narratives, and persuasive texts. In the SRSD approach, the third graders were taught to develop a plan in advance writing, modifying and elevating their writing as they implemented it. According to Kellogg (1987; cited in Graham, Harris, & Mason, 2005) a written plan may reduce the need to plan while writing, thus freeing up resources to engage in other writing processes such as translating ideas into words and transcribing words into printed text.

In raising students' metacognitive awareness and their control of writing processes, classroom interventions have been developed. Most of these interventions attempt to reduce the cognitive processing demands on the less-skilled writers by providing prompts, cues and scaffolds. Marlene Scardarmalia and Carl Bereiter (1994) developed the procedural facilitation approach that has worked effectively with elementary school students and has been adapted up through college level (Baker, 2011). Table 5 shows examples of some cues that students used while they were planning to write an academic essay. Typically, this approach involves using cues to stimulate self-questioning during planning monologues (Scardamalia, Bereiter, & Steinbach, 1984) for constructing opinion and factual essays. For example, the student can start with the cue, "A different aspect would be …" when introducing an essay that expresses his/her viewpoints.

Table 5. *Planning cues.*

Opinion Essays	**Factual Exposition**
New Idea	**New Idea**
An important point I haven't considered yet is ... A different aspect would be … A whole new way to think of this topic is … **Improve** If I could make my main point clearer … A criticism I should deal with in my paper is … **Elaborate** An example of this … This is true, but it's not sufficient so … Another way to put it would be … **Goals** My purpose … I can tie this together by …	An important distinction is … A practical benefit is … **Improve** I could describe this in more detail by adding … I could give the reader a clear picture by … **Elaborate** An explanation would be … My own experience with this is … **Goals** A goal I think I could write to … **Putting it Together** If I want to start off with my strongest idea, I'll … My main point is …

Adapted from Scardamalia, Bereiter, & Steinbach (1984)

Prompts are, therefore, provided to remind students of the steps in the planning process of what to consider when revising a paper. Often, the translation demands are reduced so that students who are overly concerned with spelling, punctuation, and handwriting are not exceedingly involved with lower level components.

Listening Comprehension

For listening comprehension, Goh (2018) highlighted strategies to enhance listening comprehension for second language learners. As listening processes occur mainly within the mind of the individual, the comprehension and learning processes for listening are less visible to teachers and learners themselves. Goh (2018) argues that metacognition and its related training provide several benefits for second language students' listening development.

First, it provides a frame of reference to help students develop their listening skills. Second, the concept of metacognition allows teachers to explore teaching students about self-managing and controlling their learning with strategies that would enhance comprehension and longer-term development of listening. Third, teachers can help students understand the challenges faced by learners through tasks that promote observations, critique and analysis to enable them to improve their listening skills. Goh (2018) suggests the following teaching strategies and considerations for listening instruction: (a) paying attention to pre- and post-listening metacognitive activities and not just on the listening activity itself; (b) including prompts to encourage students to pause, reflect, and analyse; (c) encouraging students to reflect on their strategic use of metacognitive knowledge and regulation; (d) guiding students to notice and learn about their comprehension errors; (e) embedding metacognitive activities (e.g., predicting and evaluating) within a lesson sequence; (f) discussing possible challenges for students' listening task; (g) talking about the prerequisites skills or conditions that could enhance listening comprehension; and (h) using a self-monitoring checklist of useful tactics or strategies.

Metacognition for the learning of Mathematics

Mathematics educators and researchers have been interested in whether mathematical problem-solving can be taught and if problem-solving can be taught, how this can be done (Schneider & Artelt, 2010). Researchers have recognised the importance of metacognition and mathematical problem-solving (Brophy, 1986; Lester, 1982; Verschaffel, 1999). There is a general belief among educators and researchers that metacognition can be taught to facilitate mathematical problem-solving. It is also noted that many of the factors that determine success or failure in Mathematics are metacognitive in nature (Silver, 1982). While there has been interest in the area of metacognition, research on metacognition in the domains of language, arts and reading still exceeds that in Mathematics (Schneider & Artelt, 2010).

Pólya (2004) is commonly cited for his works on mathematical problem-solving and metacognition. He proposed a model of four phases for mathematical problem-solving: (1) understanding the problem; (2) devising a plan; (3) carrying out the plan; and (4) looking back. First, the student or learner intending to solve the problem needs to be clear of what is required from the problem. Second, s/he needs to assess how to make use of whatever information that is given, makes links to the given information and unknown to come up with a plan. Third, s/he needs to put the planning into action. Last, the student needs to review the completed solution. Pólya's works have considerable influence on later efforts in metacognition and mathematics problem-solving, although metacognition is implicitly represented in his model. Researchers in this field adapt, build-on or make explicit the metacognition elements in Pólya's model.

Pressley's (1986) Good Strategy User Model, as discussed in the above subsection (more information in Appendix G) reading comprehension, reviewed the strategic, metacognitive and knowledge components of good strategy use and revised the five principles of teaching arithmetic related to Pólya's model of problem-solving in Mathematics. The model illustrates applications of teaching Mathematics and also focuses on the importance of the use of (repeated) practice to enhance mathematical problem-solving skills.

Corresponding with cognitive and metacognitive strategies, the five broad principles for good Mathematics instruction are:

a. teach strategies—explicitly teach strategies to younger and less matured learners, as strategies would be even more beneficial for the novice learners since they are new to the problem in focus;
b. teach knowledge about when, where and how to use strategies—the learning of computational and procedural mathematical skills in insolation is not enough; students need to be taught to understand when, where and how to use these strategies;
c. teach general knowledge about factors that promote strategy functioning—learners need to understand that errors are often the result of incorrect use of strategies rather than a lack of ability;
d. teach relevant non-strategic knowledge—the repeated practice of basic mathematical skills such as multiplication tables and memorising of basic facts would enhance both mathematical speed and accuracy; and
e. encourage students to practise components of good strategy use and the coordination of components—practise each component separately first and then coordinate the components over a period of time.

Garofalo and Lester (1985) incorporated metacognitive activities into their framework that comprises four categories of activities in a mathematical task: (1) orientation; (2) organisation; (3) execution; and (4) verification. Basically, orientation refers to the strategic behaviour to assess and understand a problem, which includes comprehension and analysis of the information given, assessment of familiarity of the task or problem, and assessment of the level of difficulty and chances of success. Organisation refers to the planning behaviour and the choice of actions which include identification of goals and sub-goals, and having the overall detailed plans. For execution, it involves the regulation of behaviour to follow the plans and decide on trade-offs (e.g., speed versus accuracy). For verification, it entails the evaluation of the decisions made and the outcomes of the executed plans. It is an evaluation of the earlier processes of orientation, organisation and execution.

In the local educational context of Singapore, Lee et al. (2001) and Lee et al. (2014) developed the *Problem Wheel Approach* comprising the components “given”, “find”, “picture”, “topic”, and “formulae” and their corresponding prompts as a metacognitive scheme to facilitate students to solve mathematical word problems (or problem sums). The Problem Wheel attempts to help students in their understanding and planning stage of mathematical problem-solving. With the Problem Wheel, students use question prompts to monitor and direct their cognitive resources to better understand a given problem (Lee et al., 2014). Understanding information in a mathematical word problem generally requires students to know what information is provided (given) and what information to search for (find). Students are also encouraged to draw pictures or diagrams (picture) to better visualise the relationships between what is given in the question and what they need to find. The next step involves selecting the necessary mathematical skills and knowledge to solve the word problem (topic). Students need to choose from the concepts, ideas and skills they have learned and apply them to solve the mathematical problem in focus. Ultimately, students may be able to derive their own method (formulae) to the question at hand.

Metacognition for the learning of Science

There is also growing interest among Science educators and researchers in examining how metacognitive instruction can facilitate and enhance students’ learning of Science knowledge and concepts. Although it is generally accepted that metacognition is central to the learning of Science and in education in predicting academic success, this understanding has yet to be methodologically translated into the Science curriculum.

In a systematic review of 178 studies published in peer-reviewed journals from 2000 to 2012, Zohar and Barzilai (2013) noted that a wide range of instructional practices for fostering students’ metacognition in Science have been employed. In summary, these instructional practices are (1) explicit instruction—this does not automatically imply the use of direct instruction; explicit instruction can also take the form of a more constructivist approach; (2) practice and training—lessons that encourage the application of metacognitive thinking; (3) use of metacognitive prompts such as cues, questions or probes; (4) teacher- or student-led metacognitive discussions that involve group discourse with purposeful activation of greater metacognitive awareness; (5) metacognitive writing that takes the form of journals or reports in conventional paper-and-pencil or digital formats with the purpose of reflecting on one's thinking; (6) metacognitive modelling; (7) concept mapping and other visual representations for visualisation and to put students' thinking into a pictorial format; and (8) ICT use for metacognitive instruction where technology is used as a tool to facilitate metacognitive thinking.

In this regard, the instructional strategies for improving self-regulation in the learning of Science, as proposed by Schraw et al. (2006), are outlined below.

Inquiry-based learning

Inquiry-based learning is closely associated with the learning of Science. It seeks to create a learning environment for students to construct their own knowledge and understanding, to ask questions, and to find their own answers with the guidance of the teacher. Metacognition is facilitated when students monitor their own learning through guidance and modelling by the teacher.

Embrace collaborative support

Embracing collaborative support through peer instruction and thinking aloud together is another strategy. Collaboration among students and teachers has become an important and also essential component in education. Collaboration between and among students and teachers provides opportunities for learning from one another, especially in instances where students or teachers share explicit examples or steps to perform a task. Explicit discussions among members facilitate the learning of Science concepts through clarification, questioning, and self-evaluating one's learning. Students can be encouraged to participate in thinking aloud together as a means to promote the acquisition of metacognition and self-regulated learning.

Strategy and problem-solving instruction

Strategy and problem-solving instruction help students to focus their attention by providing specific procedures for how common problems can be solved. Metacognition would be necessary to facilitate the acquisition of strategies before these strategies become automated. Strategy instruction also seems to be most effective for younger and under-achieving students. Examples of cognitive strategies include self-checking, creating a good study environment, planning and goal-setting, reviewing, summarising and seeking teacher or peer assistance.

Construction of mental models
Construction of mental models of scientific phenomenon is another important component of the learning of Science. Students need mental models to think metacognitively for learning Science, especially for the more complex systems and concepts. The four components of the mental model construction are model construction, model quantification, model interpretation and model revision. These are metacognitive strategies that help build relevance and links between topics learnt and currently learning.

Technology
Technology can be used to support self-regulated learning and create Science mental models, serving as a communicative and collaborative medium between learners and teachers.

Personal beliefs
Personal beliefs such as students' self-efficacy and epistemological beliefs affect students' metacognition and self-regulated learning. Students who are more self-efficacious or motivated are also better self-regulators as they are likely to be more metacognitive.

Metacognition for the learning of humanities subjects – Geography, History and Social Studies
Research literature on metacognition in the teaching and learning of humanities subjects like Geography, History and Social Studies are not so common as compared to subjects like English Language and Mathematics. Just like the teaching and learning of English Language, Mathematics and Science, similar teaching strategies were recommended for the humanities subjects. Inquiry-based learning, collaborative project work, modelling of metacognitive thinking, use of mind maps and explicit instruction based on a constructivist model

are among the techniques suggested (Aydin, 2011; Bean et al., 1986; Brickell & Herrington, 2006; Ciullo & Dimino, 2017; Hooghuis et al., 2014; Kriewaldt, 2006; Roberts et al., 2014) with some degree of subject specificity. For instance, the focus for Geography was on the use of inquiry, mind maps, and relationship between man and the environment and history. For History, the focus was on better comprehension, understanding, retention and retrieval of historical content, sequences and events. Many of the suggested teaching strategies require a more student-centred, constructivist approach but the teacher-centred and lecture styles and approaches of instruction are still a common sight in many of our classrooms (Hooghuis et al., 2014; Roberts et al., 2014). Often, this poses a challenge to the facilitation of metacognitive and higher-order type of thinking among our learners.

The following subsections are brief elaboration of the studies on how metacognition strategies are used in the teaching and learning of Geography, History and Social Studies.

Geography

In the teaching of metacognition in Geography, a number of authors have proposed the use of inquiry-based approach within the constructivist paradigm (Aydin, 2011; Brickell & Herrington, 2006; Kriewaldt, 2006). Geography is a science that examines the relationships between people and Earth, what people are doing as a result of these relationships and what they can do (Aydin, 2011). Similar to the teaching and learning of science, cooperative learning, problem-based learning and project-based learning are suggested. These approaches can better facilitate students' assimilation, accommodation and internalisation of new information and knowledge through observation and collaborative work with their peers and guidance from their teachers. Brickell and Herrington (2006) reported their attempt with e-learning environments to immerse students in authentic problem-based learning. Their design of a real world Geography problem was embedded within an online environment that was coupled with onsite data collection. Kriewaldt (2006) recommended that classroom environment should encourage more active and constructive learning processes, with a trusting climate. She suggested that reflection should be encouraged and must be explicit, valued and practised. Reflection could take the forms of journal writing or logs and facilitated through conferencing (as in discussion with teachers and peers) with students. She also further suggested modelling by teachers, improving regulation of cognition (e.g., planning, monitoring and evaluating), facilitation of group interaction among students, and self and peer assessment.

While the *Thinking Through Geography* (TTG) remains a well-known approach for geographical education in Dutch secondary schools, Hooghuis et al. (2014) looked at why the well-known TTG strategies had limited impacts on teaching of geographical reasoning after a decade of implementation. According to the authors, the TTG approach focuses on developing both geographical knowledge and higher-order thinking skills—classifying, comparing, relating, and evaluating—that were essential for analysing situations and developments, and for decision-making. The TTG developed diverse Geography exercises, encouraged group work among students and facilitated students' reflection. However, Hooghuis et al. (2014) noted that the TTG failed to take full advantage of the strategies and a major problem lay in the teachers' facilitation of the reflective discussions with students.

Geographical thinking requires reflective thinking—a form of metacognitive thinking—about the relationship between mankind and environment, with a focus on determining what to do in situations where location matters. Reasoning from the geographic perspective requires an open and inquisitive mind, higher-order thinking skills, and geographic knowledge. Good geographical thinkers therefore have both general and deep domain-specific knowledge. Teacher responses, however, revealed that teaching and learning of geographical reasoning as more feasible and desirable for students at higher education levels (i.e., Grades 10 to 12) rather than at lower grade levels (i.e., Grades 7 to 10). Most teachers also reported that lessons were used to prepare for tests, examinations and geographical research by students. Thus, there was relatively limited use of teaching strategies such as modelling, argument mapping and structuring, and collaborative small-group discussions with regard to geographical problems. Geographical reasoning seemed to reside within and driven by the content of the course book, probably a result of reasons associated with (1) teachers' preference for teaching declarative and procedural knowledge, which they felt easier to teach than reasoning as the latter is more cognitively demanding; (2) sociocultural and organisational issues linked to the use of geographical reasoning; and (3) a lack of pedagogical content knowledge among teachers. Thus, the impact on the use of geographical reasoning from TTG strategies appeared limited. Blankman, van der Schee, Volman, and Boogaard (2015) and Ormrod and Cole (1996) recommended more attention to be given to pedagogical content knowledge, focusing on the how, why and what to teach Geography.

History

Metacognition in the teaching and learning of History as a subject is directed towards facilitating students' comprehension of historical content, sequences, and events. Within this subject-domain, there is a body of research that focuses on improving students' historical thinking and reasoning by teaching the disciplinary thinking process (Azevedo & Aleven, 2013; Pellegrino, 2007; Ponnusamy, 2010; Trombino & Bol, 2012; Wineburg, 1991, 1999). Work in this vein is aligned with that of Bransford et al. (2000), as discussed earlier (*Functions of domain-generality and domain-specificity*).

A distinct feature of historical thinking is the ability to sort and authenticate evidence from a myriad of sources (Trombino & Bol, 2012) which is highly dependent on the student's capacity to engage in self-regulated learning and employ metacognitive strategies (Azevedo & Aleven, 2013). Historical thinking activities include learners presenting views on a specific era of history and offering justifications as they unveil accounts of how these historical events occurred, as seen in the study conducted by Pellegrino (2007). Students make sense of the event(s) by examining historical evidence that either reaffirms or contradicts their viewpoints, and through this process, recognise the fluidity and complexities of historical events.

Wineburg's (1991, 1999) seminal works on historical thinking and how historians read historical documents are instrumental in mapping the metacognitive strategies used by historians. In a study conducted by Wineburg (1991), think-aloud protocols from eight historians and eight high-school students were collected as they read through documents about the Battle of Lexington during the Revolutionary War. The study noted that historians tended to rely more on general problem-solving strategies when they encountered a document beyond the scope of their specialisations or a new document. Other differences included the historians (or the "experts") who engaged in a process of discovery for new knowledge, a phenomenon rarely occur with the students. Three main heuristics prominently emerged in the review of the protocols: (a) corroboration, where documents are compared against each other; (b) sourcing, where the source of the document is identified and noted before looking at the main text; and (c) contextualisation, placing the document in terms of events and concepts surrounding it. The heuristics identified here resonate with Ciullo and Dimino's (2017) advocacy for disciplinary literacy skills in the teaching of historical reasoning, enacted through examining a document's source for bias, studying the context (as in the time period) in which an article was written, and comparing different documents to triangulate arguments. This approach of using heuristics in the learning and teaching of history also reflects the metacognitive process which learners critically engaged with when they encountered an unfamiliar historical document.

In an experimental-based study, Bean et al. (1986) reported their findings on students who were split into three groups with different conditions. The main aim of their experimental research was to examine students' regulation of cognition through a repertoire of study strategies believed to be able to facilitate students' retention and retrieval of information. Two of the groups received systematic instruction in the development of graphic organisers (similar to that of a mind map) and the third, instruction on outlining. One of the two groups that received instruction in the use of graphic organisers, and also previous training in summarisation and question generation during an earlier study, outperformed the rest of the groups. Additionally, this group did better in the quiz and written recall protocol. According to the authors, graphic organisers provide a more vivid depiction of the interrelationships among concepts as compared to outlining, which is more linear in nature. Based on Bean et al.'s (1986) observation, students who were in the graphic organiser groups had to sort and reconstruct text concepts in order to depict their interrelationships. This process requires higher-order thinking and, as a consequence, undoubtedly encourage integration, retention, and retrieval of text concepts. (Bean et al., 1986, p. 166).

In another more recent study of middle school History, Roberts et al. (2014) examined the impacts of Promoting Acceleration of Comprehension and Content through Text (PACT) and Team-Based Learning (TBL) in facilitating students' recall of History content. The PACT intervention mainly consisted of instruction protocols aiming to enhance students' reading comprehension, engagement, student collaboration and frequent opportunities to discuss and elaborate on information as part of processing, accompanied by ongoing teacher feedback. The authors argued that students in PACT classrooms may outperform their counterparts in comparison classes because PACT engaged and supported deep cognitive processing (with elaboration and discussion) at the time of learning, thereby allowing students to better conserve and reallocate their cognitive and metacognitive resources for encoding content. In Roberts et al.'s (2014) words, PACT may moderate the relationship between metacognitive elaborative rehearsal and content retrieval. However, it was also highlighted that the lecture-oriented or teacher-centred approaches that prevail in many middle school History classrooms are motivated by teachers' interest in covering content and syllabus for high stake examinations. It was thus not easy to implement PACT and TBL as both teachers and students struggled with student to student collaboration, and on teacher to student discourse.

Social Studies

Philbrick (2009) examined the effects of explicit teaching of metacognitive strategies within the context of Social Studies content instruction (i.e., within the social study instruction time). Six 5th grade classrooms in a school were selected with two classes to receive reading strategies in Social Studies, another two learned identical strategies in their reading class that were unrelated to Social Studies and the last two classes served as control, receiving the same Social Studies context without the reading strategies. The first group (i.e., reading strategies within the context of Social Studies) outperformed the other two groups and the second group (i.e., reading strategies) outperformed the control. Lambert (2009) noted that pupils need to be taught to think in a specific context rather than in isolation. The metacognitive strategies taught were similar to that of reading comprehension. They included (a) think-aloud during the reading; (b) summarising a passage; (c) predicting the cause and effect; and (d) questioning themselves and the author. The teacher in the first group emphasised that the strategies taught were for students to better understand the texts within the Social Studies context.

Ciullo and Dimino (2017) suggested the use of scaffolded instruction for students with learning disabilities in Social Studies classes. Their main focus was to provide support with the explicit teaching of strategies through the “I do, we do and you do” approach that would promote reading for understanding and writing in Social Studies. They outlined three strategic interventions for which scaffolding of cognitive strategies during Social Studies instruction have played an important role. These interventions were: (a) collaborative strategic reading; (b) thinking before reading, think while reading, think after reading (or TWA in short); and (c) historical reasoning. For collaborative strategic reading, students were taught to preview (i.e., activate prior knowledge and scan through the subheadings and keywords), click and clunk (i.e., identify unfamiliar words), get the gist (i.e., identify the main ideas of the passage to find the “who” or “what”), and wrap up (i.e., students celebrate to discuss the text they read) when reading Social Studies texts. The TWA followed the self-regulated strategy development instructional model where students were introduced to why TWA could support them in monitoring and applying comprehension strategies, taught when and how to use TWA that was and assisted with practice and teacher’s guidance.

Discussion

Teachers and educators are interested in whether metacognitive knowledge and self-regulated skills would be useful to enhance or facilitate students’ learning and performance. In particular, whether such knowledge and skills will further facilitate learning transfer and help students manage and solve problems they have never encountered before. This is particularly crucial in today's VUCA (volatile, uncertainty, complex and ambiguous) world where the ability to respond to unfamiliar situations and problem-solving is met with no readily available or prescribed solutions. Hence, there is a need to rethink about what is generally accepted as metacognition and how it can be effectively taken up to engage students with learning at school and beyond.

The potential of metacognition and metacognitive skills to enhance students' performance is well articulated in the research literature on metacognition. A heartening point is that metacognition explains more variance than IQ does with respect to students' performance (Veenman et al., 2006; Veenman et al., 2004). It is widely accepted that metacognition has either two or three sub-components—metacognitive knowledge, metacognitive regulation or skills, and metacognitive experiences. In essence, metacognition may be viewed as a function of metacognitive knowledge, self-regulation and skills, experiences and motivation. The interplay of these elements contributes to students' metacognition.

Measurement of students' metacognition is another area of interest among researchers and practitioners. There are two considerations for the measurement of metacognition—the "when and what" and the "how". It is generally accepted that students' metacognition can be measured either "online" or "offline", that is, synchronously or asynchronously. As with all forms of assessment, they have their own strengths and weaknesses, and this leads to the recommendation of a multi-method approach towards the assessment of students' metacognition. In recent years, researchers have also used the functional magnetic resonance imaging or functional MRI (fMRI) imaging and Functional Near-Infrared Spectroscopy (fNIRS), coupled with assessment methods that are unique to neuroscience, with the aim of having a more objective means to assess students' metacognition (Metcalfe & Schwartz, 2016; Molenberghs, Trautwein, Böckler, Singer, & Kanske, 2016; Shimamura, 2000).

One of the commonly debated topics in the field of metacognition is whether metacognition is domain-specific or domain-general. While some have argued for the former, the rest are more inclined towards the latter. Both perspectives have their own justifications and, in our opinion, both are equally legitimate. There is metacognitive knowledge that is specific to the learning of reading or listening comprehension, Mathematics problem-solving, Science inquiry, and the learning of humanities subjects Geography, History and Social Studies. For instance, applying the “what”, “how”, and “when” strategies to the different types of content learning largely typifies the learning of the humanities. While this is so, there are also more generic metacognition activities such as planning, monitoring, and evaluating. Monitoring of one’s understanding through periodical self-testing of concepts and procedural skills learned to ensure knowledge and skills retention is one example. Such regulative skills are generic regardless of whether it is learning and acquiring a language, mathematical skills or physical psychomotor skills. In fact, some have argued that the development of metacognitive knowledge and skills begin with domain specificity and become more domain general with practice, experience and age (Borkowski et al., 2000; Neuenhaus et al., 2011; Schraw, 1998).

Next, we turn our attention to how metacognition can be facilitated by teachers for our students. While there have been proponents of metacognition who recommended more generic approaches for teachers and schools to promote or facilitate general metacognitive awareness among students, most of the research studies in this field are disciplinary specific, as seen in the research literature that we have reviewed earlier in the learning of English Language, Mathematics, Science, Geography, History and Social Studies. As noted in the earlier section “Promoting Metacognitive Awareness”, metacognitive strategies are used to facilitate students’ learning in reading and listening comprehension for English Language, problem-solving for Mathematics, inquiry for Science and Geography, students’ comprehension of content, sequences and events for History and collaborative reading strategies for Social Studies. For teaching and learning of the various subjects and content areas mentioned, metacognitive strategies seem to be focusing on very different aspects of learning (i.e., listening or reading comprehension, problem-solving and inquiry-based learning) but they follow the common and fundamental principles of generating successful metacognitive instruction. The three fundamental principles of successful metacognition instruction, as identified by Veenman et al. (2006) are: (1) embed instruction in the content matter in ways that encourage students to form connections between metacognitive knowledge and metacognitive strategies; (2) explicitly inform students about the usefulness and benefits of metacognition so that learners would be more aware and thus, learners are likely to make a conscious effort to engage in metacognitive activities; and (3) provide prolonged practice and training for more effective, efficient, and sustained application of metacognitive activities (Zohar & Barzilai, 2013).

Last, we turn our attention to the teachers—the ones who enact the metacognitive instruction to our students. Although the argument that facilitating and instructing metacognitive activities presuppose teachers to be metacognitive and be aware of their own metacognition seems logical, there are limited research studies and attention in this area until in the recent years (Balcikanli, 2011; Jiang et al., 2016; Kallio et al., 2017). We believe that it is critical for teachers to see the potentials of metacognitive awareness and instructions. Professional development efforts would be necessary for them to better embrace such an approach to benefit their students educationally.

Recommendations and Implications

This paper has reviewed the literature on the concept of metacognition, examining what counts as metacognition in the educational context, how metacognition is measured, and the metacognitive strategies that are commonly used in language and literacy, Mathematics, Science and humanities. The relevance of understanding metacognition and its related concepts can be appreciated from the broader perspective of the changing educational landscape in Singapore and abroad. Education should prepare learners to tackle collaborative problem-solving that lack clear solutions. We believe that a strong grasp and awareness of how to use metacognitive strategies effectively can help learners to reflect on their ideas, hone their analytical skills, strengthen their critical and creative thinking capacities, and demonstrate initiative. Specifically, the ability to evaluate new inputs or information and perspectives judiciously, build new capacities and strengthen autonomy will increasingly be vital today and in the near future. Crucially, this harks back to the fundamental understanding of how one can be metacognitive in situations that are highly complex or unimagined, interdisciplinary in nature and spanning multiple domains (social, economic and environmental) that are beyond the everyday discipline-based contexts that students encounter. Approaches that lead learners to question their own beliefs and those of their peers, and attempt to enhance reflection, metacognition, and the construction of new knowledge should be high on the agenda of every education system. This leaves traditional educational institutions with much to experiment with alternative structural formats and strategies for learning and teaching that respond more flexibly to individual learners' needs.

Implications and recommendations for policy and practice

As the research literature has shown earlier, the teaching of metacognitive thinking can facilitate students' learning and lead students to be better problem-solvers. This is a trait that is required by our students for the economy of the future.

As argued by Schraw et al. (2006) and Zohar and Barzilai (2013), the training and learning of metacognitive thinking, strategies and skills would be better done over an extended period of time, not in isolation and only undertaken within one to two subject areas. Hence, it would be sensible to integrate the teaching of metacognition into various subject content areas like English Language, Mathematics, Science, the humanities or even the arts. Perhaps, one common efficiency-based question is why not take the teaching of metacognitive thinking out of the subjects as an independent program as this will not "disrupt" or "interfere" with the current modus operandi. This is not ideal because, as suggested by various research studies, the development of metacognitive thinking seems to develop from the domain specific arena and move towards a more generic form. It would be necessary for the teaching of metacognitive thinking to start with and be linked to specific subject content area. In addition, taking into considerations how current teaching and learning are being structured (i.e., by school timetabled hours), it would be more viable for such teaching to be incorporated into the subject syllabus and curriculum as there are subject specificity in the teaching and learning of metacognition.

In addition, as suggested by Hofer and Pintrich (1997) and Paris (2002), it is necessary and crucial to consider students' motivation and beliefs when facilitating the acquisition of metacognitive thinking in our students; they are important mediators between metacognitive thinking and students' performance. Students' metacognitive strategies and skills will not be put into productive use if they are not motivated or do not believe that the strategies and skills are going to help them in their learning or enhance their problem-solving capabilities. Hence, it is important to stress the importance of having a positive classroom climate with a growth mindset, where students are socialised into the importance and effectiveness of metacognitive strategies in their learning and future problem-solving abilities.

Teachers play an important role in teaching metacognitive thinking to our students. Not only do they need to be equipped with the strategies (e.g., explicit teaching of metacognitive strategies, think aloud protocols, inquiry-based, collaborative and constructivist approach), but they also need to believe in the potentials of these metacognitive skills and strategies for their students. If teachers do not think or feel that these strategies are useful for their students to be better learners and problem-solvers, then the likelihood of these strategies to be taught would be low. Teacher training institutions may want to deepen teacher professional development in metacognition. Training and teacher professional development alone may not be adequate; constant and extended dialogues (formal and informal) among and between school administrators, researchers and teachers would be necessary.

In our haste to facilitate the learning of metacognitive skills and strategies among our students, it is important to remind ourselves and our teachers that metacognition is not the panacea and elixir for all learning issues. It is one of the several means to foster deeper and more complex thinking; fluency in the basic content knowledge still forms the foundation of more complex higher-order type of thinking (Derry, 1990; Pressley, 1986, 2002). This highlights the importance of knowing our students well, in terms of their prior knowledge, so that more advanced and sophisticated forms of knowledge and thinking could be layered upon what they already know. Teachers also need to be constantly aware of the need to create a positive and conducive classroom climate for our students to be engaged and motivated for learning, and to become confident individuals who will be ready to face the challenges of the future economy.

Implications and recommendations for research

Assessment of students' metacognitive knowledge, regulation and experiences remain contentious after 40 years of research in this field. As mentioned above, the "when" to measure is not so much an issue as students can be queried before, during or after a certain task or learning situation. More research would be needed to look into the "what" and subsequently and consequently the "how" to measure; the "what" will determine "how" to measure. The components (i.e., knowledge, regulation and experiences) and sub-components (i.e., declarative, procedural and conditional knowledge; planning, monitoring and evaluation regulations; positive and negative affect) of metacognition need further clarification and refinement in their definition into even more operational and behavioural terms. It is also noted that the measurement of experiences may be challenging. In addition, current assessment methods (e.g., survey questionnaires, observations, interviews and tests) would need to be further refined and new methods need to be developed to measure more accurately the different metacognition components and their sub-components.

From the review of the literature, the teaching of metacognitive thinking and strategies seems to be associated more closely with English Language and Mathematics. While there are research studies in science on inquiry-based approaches and methods, studies into the humanities with regard to the teaching and learning of metacognitive thinking, especially in the Singapore context, are limited. Due to subject and domain specificity, it would be beneficial to embark on metacognition research in the teaching of the humanities subjects.

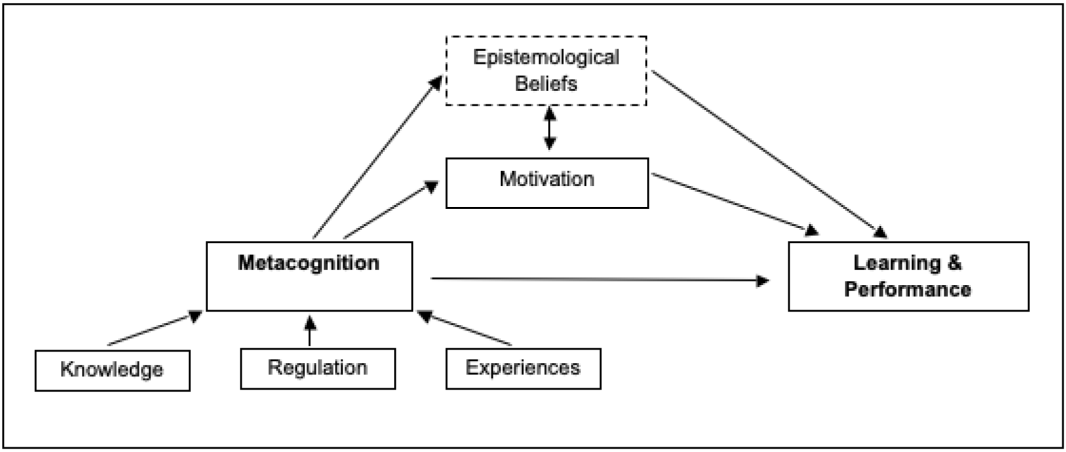

Figure 2. *Linkage between metacognition and learning and performance mediated by motivation and beliefs.*

When considering the effectiveness of metacognitive thinking and strategies for teaching and learning, the motivation of students plays an important role. The links between metacognitive thinking and motivation has been an area of interest to researchers in the field of cognitive science. One possible area of research that deserves our attention could be the linkage between students' epistemological beliefs and their metacognitive awareness and thinking. Logically speaking, students' metacognitive strategies could only be effectively activated and operationalised if they believe in these strategies and that they are able to learn and solve problems more effectively with them. Figure 2 depicts the possible linkage between metacognition, motivation and epistemological beliefs.

Last, there is another area that is relatively under researched—the metacognition of teachers. It is not unreasonable for us to expect our teachers to be metacognitive thinkers and problem solvers so that they could in turn guide our students to achieve greater metacognitive awareness and thinking. If teachers were to teach students to think in a metacognitive way, they need to be metacognitive themselves, and be aware of their own metacognition first.

Conclusion

Forty years on after the term metacognition was coined by Flavell (1979), there remains fuzziness over how the term is defined as well as the great interest metacognition has generated among educational researchers and practitioners. Researchers in this field remain enthusiastic about metacognition because of its potentials and promises. Basically, metacognition is made up of three sub-components—metacognitive knowledge, skills and experiences. Other than metacognitive knowledge, the regulative skills, motivational and emotional elements are important functions of metacognition. Research on metacognition has also been pushing the boundaries to explore how students' metacognition can be more objectively measured and assessed. The fMRI or fNIRS, with its advanced imaging techniques to detect brain activities, can be seen as a recent addition to the existing conventional research methods in uncovering new and comprehensive insights into the cognition of learners.

What is even more challenging and vital is how metacognition could be facilitated or to put it simply, how it can be taught or instructed rather than residing as a skill within the cognitive mind of the individual. *Explicit* and *prolonged instruction and practice* is necessary. Teachers also need to make the *linkage between content specific metacognitive knowledge and metacognitive strategies or skills*. It is also believed that a *social constructivist approach* can be more successful in enabling students to acquire more high-order type of cognition with their fellow peers and teachers through in-depth discussions. *Probing questions and prompts* could be used by instructors and teachers to facilitate learning and more metacognitive type of thinking. *Teacher thinking aloud and modelling* of metacognitive thoughts and actions would also be helpful to students. In addition to the considerations mentioned above, metacognition instruction needs to take into account of the differences in the subject content specificity. For instance, the difference in the focus in language learning activities for reading or listening comprehension and the strategies and tactics employed by students while engaging in problem-solving tasks in Mathematics; there are similarities as well as differences in the ways metacognition instruction is played out for different disciplines or content areas. For metacognitive training and learning to be effective, it is imperative for learners to be fluent with the fundamental knowledge and competence expected of the disciplines in question. A good grasp of number sense and arithmetic computational skills, for example, would help learners to maximize the benefits and potentials of metacognitive strategies specific to Mathematics and the concept of whole numbers.

Last, it is also important not to neglect the teachers in the metacognition–student learning equation. It is reasonable to expect teachers to be metacognitive if we expect them to facilitate and teach it to their students since they are critical mediators of students' learning. Continuous and persistent professional development efforts are necessary for teachers to understand the concept, components, and sub-components of metacognition so that they can design instruction that facilitates this higher-order thinking among our students and transfer their metacognitive knowledge and skills to their students as ways of preparing for the constantly changing world and of meeting the challenges of the future economy.

Acknowledgement

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Appendices – Metacognition assessment instruments and protocols

Commonly used self-report instruments

Among the list of available methods for assessing metacognition, self-report questionnaires and surveys are the most cost-effective and easiest to administer. Self-report questionnaires and surveys are typically associated with larger scale studies and are commonly used by researchers and practitioners with limited resources or access to students' class time. Surveys are cheap and quick but easily corrupted with biased and unreliable responses. Within the field of metacognition, self-report questionnaires and surveys are often critiqued on their validity of score interpretations (Harrison & Vallin, 2018). When viewed from the perspectives of motivation and student engagement, self-report questionnaires and surveys face similar criticisms. Yet, despite these criticisms, self-report questionnaires and surveys remain widely used for practical reasons such as ease of administration in terms of time and logistical requirements for both researchers/administrators and participants/students. With the extensive use of self-report questionnaires and surveys, Berger and Karabenick (2016) propose for further improvements to these instruments rather than arguing against their use. In investigating students' metacognition, the three frequently used self-report instruments (Harrison & Vallin, 2018; Harvey & Chickie-Wolfe, 2007; Meijer et al., 2013; Schraw, 2000) are:

(1) Metacognitive Awareness Inventory (MAI) by Schraw and Dennison (1994)

(2) Motivated Strategies for Learning Questionnaire (MSLQ) by Pintrich and De Groot (1990)

(3) Learning and Study Strategies Inventory (LASSI) by Weinstein, Palmer, and Schulte (1987)

Based on the original MAI instrument, the Junior Metacognitive Awareness Inventory (Jr MAI) was developed by Sperling, Howard, Miller, and Murphy (2002) for students from Grades 3 to 9 (i.e., aged 9 to 15, which is equivalent to students from Primary 3 to Secondary 3 in Singapore). The MSLQ and Jr MAI are well documented in the field of metacognition and they can be easily accessed by students since the instruments are easily available and are economically free. In terms of LASSI, it is a 10-scale, consisting of 60-item assessment of students' awareness about and use of learning and study strategies related to skill, will and self-regulation components of strategic learning. As a point to note, LASSI is not included in the discussion of this paper as it is currently only available online with H&H Publishing (http://www.hhpublishing.com/_assessments/lassi/) with a fee.

Appendix A

The Junior Metacognitive Awareness Inventory – Jr MAI

The Jr MAI developed by Sperling et al. (2002) is used to assess the students' level of metacognitive awareness and their academic performance in English, Mathematics, Science and Mother Tongue languages. The Jr. MAI was adapted from the Metacognitive Awareness Inventory and developed by (Schraw & Dennison, 1994) for adults. Although there are other metacognition and self-regulation scales available (Tock & Moxley, 2017; Tuncer & Kaysi, 2013), the Jr MAI was specifically developed for use with students from Grade level 3 to 9, or Primary 3 to Secondary 3 in the local context, as noted earlier. This study used the three categories of knowledge of cognition (i.e., declarative, procedural and conditional) and three categories of regulation of cognition (i.e., planning, monitoring and evaluation). It supported a two-factor view of metacognition (i.e., knowledge of cognition and regulation of cognition) with limited evidence of connections between metacognition and outcome performance measures.

Sperling et al. (2002) conducted two studies to investigate measures of students' metacognition with two versions of the Jr MAI. Version A is made up of 12 questions and serves Grade 3 to 5 students (aged 9 to 11) or Primary 3 to 5 of the Singapore equivalent. Version B is made up of 18 questions, with 6 additional questions to Version A, and caters to Grade 6 to 9 students (aged 12 to 15) or Primary 6 to Secondary 3 of the Singapore equivalent. Subsequent validation studies by Kim, Zyromski, Mariani, Lee, and Carey (2017) and Ning (2017), employed exploratory and confirmatory factor analyses supported a two-factor model of cognition with two underlying factors that correspond to knowledge and regulation of cognition.

Table A1, as shown below, illustrates the survey questions and the corresponding association with the two sub-constructs of knowledge and regulation of cognition. Version A of the inventory is on a 3-point Likert scale of – "never", "sometimes" and "always" – it is made up of questions from 1 to 12. As for Version B, which is on a 5-point Likert scale of "never", "seldom", "sometimes", "often" and "always", is made up of questions from 1 to 18.

Sperling et al. (2002) noted that Jr MAI measured metacognition more broadly than existing measures and recommended it as an overall measure of knowledge and regulation of cognition as a way of reducing reliance on individual factor scores.

Table A1. *The Junior Metacognitive Awareness Inventory (Jr. MAI)*

No.	Junior Metacognition Awareness Inventory Items	Item conceptual affiliation
1.	I can make myself learn when I need to.	Knowledge
2.	I learn best when I already know something about the topic.	Knowledge
3.	I use my learning strengths to make up for my weaknesses.	Knowledge
4.	I use different learning strategies depending on the task.	Knowledge
5.	I know when I understand something.	Knowledge
6.	I know what the teacher expects me to learn.	Knowledge
7.	I learn more when I am interested in the topic.	Knowledge
8.	I try to use ways of studying that have worked for me before.	Knowledge
9.	I sometimes use learning strategies without thinking.	Knowledge
10.	When I am done with my schoolwork, I ask myself if I learned what I wanted to learn.	Regulation
11.	I ask myself if there was an easier way to do things after I finish a task.	Regulation
12.	I draw pictures or diagrams to help me understand while learning.	Regulation
13.	I really pay attention to important information.	Regulation
14.	I think of several ways to solve a problem and then choose the best one.	Regulation
15.	I ask myself how well I am doing while I am learning something new.	Regulation
16.	I occasionally check to make sure I'll get my work done on time.	Regulation
17.	I think about what I need to learn before I start working.	Regulation
18.	I decide what I need to get done before I start a task.	Regulation

Items 1 to 4 – conditional knowledge; 5 to 7 – declarative knowledge; 8 to 9 procedural knowledge

Items 10 to 11 – evaluation; 12 to 13 – information management skill; 14 to 16 monitoring; 17 to 18 – planning

The Jr MAI has also been revalidated by Ning (2017) in a study with children in the Asian setting, specifically with a sample from primary school students in Singapore. According to Ning (2017), the Jr. MAI can be useful for large-scale survey research in which traditional verbal assessments such as interviews and think-aloud protocols would be infeasible. As such, the Jr. MAI offers a way of assessing children's metacognition and provides opportunities for more large-scale cross-cultural studies that would allow researchers to yield a better understanding of children's metacognitive processes (Ning, 2017). Ning (2018) further re-examined the psychometric properties of the two versions of Jr MAI with Singapore students and reported that the instruments demonstrated good measurement precision with no differential item functioning detected across gender and ethnic groups. A total of 1990 students were involved in this round of Rasch analysis, with 819 Primary 5 and 1171 Secondary 3 students.

Appendix B

The Motivated Strategies and Learning Questionnaire - MSLQ

With the exception of measuring the knowledge component of metacognition, the MSLQ is one of the most widely used instruments for measuring students' motivation and the self-regulation aspects of metacognition (Tock & Moxley, 2017). The MSLQ, including its subscales has been used with different student groups in different fields in many countries (Karadeniz, Buyukozturk, Akgun, Cakmak, & Demirel, 2008).

The MSLQ-College is a survey instrument with 81 items. It is divided into two different sections – motivation and learning strategies. The motivation segment consists of 31 items that assess students' goals and value beliefs (i.e., intrinsic goal orientation, extrinsic goal orientation, and task value) for a course of study, their beliefs about their skill (i.e., control belief, self-efficacy for learning and performance) to succeed in a course and their anxiety about tests in a course. The learning strategies section consists of a total of 50 items, assess three main constructs, and nine subscales: cognitive strategies (i.e., rehearsal, elaboration, organisation and critical thinking), metacognitive strategies (i.e., self-regulation) and resource management (i.e., time and study environment, effort regulation, peer learning and help seeking) (Pintrich, Smith, Garcia, & McKeachie, 1991). The first 3 cognitive strategies (i.e., rehearsal, elaboration and organisation) are memory strategies and reveal the origins of the scale in memory strategies for both MSLQ and LASSI, The MSLQ-High School (Pintrich & De Groot, 1990) is an abridged version for students aged 14 to 16.

The learning strategies section of the MSLQ-College survey has been statistically validated with 441 Year 11 students within the Singapore secondary school system (Chow & Chapman, 2017). Chow and Chapman (2017) tested three models for the learning strategies section of the instrument. Model 1 included all items for all the learning strategy subscales as one factor, Model 2 tested a three-factor model with items grouped into three broad sub-constructs (cognitive, metacognitive, and resources management), and Model 3 tested a nine-factor model based on the nine subscales of the learning strategies within the MSLQ (i.e., rehearsal, elaboration, organisation, critical thinking, self-regulation, time and study environment, effort regulation, peer learning and help seeking).

The MSLQ-High School was locally, revalidated with a total of 780 secondary school students (aged 13 to 16) from eight Singapore secondary schools by Liu et al. (2012), with 393 completing the MSLQ-High School version and a subsequent 387 students taking the modified MSLQ (i.e., 28 items). Liu et al. (2012) reduced the 44-item MSLQ-High School and supported a 28- items MSLQ-High School with five factors (i.e., intrinsic value, self-efficacy, test anxiety, learning strategies and lack of self-regulation). This 28-item MSLQ-High School was further revalidated and refined with 3 items removed (Ng, Wang, & Liu, 2017). In summary, these above studies provide the validation of the MSLQ-High School version for students in the Asian context. Appended below is the list of the 28 items found in Table B1. The items are further unpacked for a better understanding and appreciation of the constructs.

Although the MSLQ is a well research and cited instrument, there are some issues with it. First, the strategies mentioned are not connected to any context, events or subjects and so they are generic and susceptible to self-serving biases when participants or students want to look good or virtuous. It is like statements that say “I am honest” without any context or the judgement. Second, the statements have no frequency index. So, for instance, the first item (LS1), a participant or student might respond ‘Strongly Agree’ because he/she recalls rehearsing facts sometime in the past as a study aid. But using a strategy once, or thinking you used it, is a generic memory unrelated to any task or event and doing a strategy once is not as desirable as doing it often so the assessment does not assess frequency of use. Third, the survey items do not assess students’ beliefs about the efficacy of the strategy, the utility of the strategy and whether using the strategy is worth the effort of the student in a given context.

Table B1. *The modified 28-item MSLQ-High School*

Construct	**Items**
LS1	When I study for a test, I practice saying the important facts over and over to myself.
LS2	I use what I have learned from old homework assignments and the textbook to do new assignments.
LS3	When I am studying a topic, I try to make everything fit together.
LS4	When I read materials for this class, I say the words over and over to myself to help me remember.

(Continued)	
LS5	I outline the chapters in my book to help me study.
LS6	When reading, I try to connect the things I am reading about with what I already know.
LS7	I ask myself questions to make sure I know the material I have been studying.
LS8	Even when study materials are dull and uninteresting, I keep working until I finish.
LS9	Before I begin studying, I think about the things I will need to do to learn.
LS10	When I'm reading, I stop once in a while and go over what I have read.
SE1	Compared with other students in this class, I think I know a great deal about the subject.
SE2	Compared with other students in this class, I expect to do well.
SE3	I am sure I can do an excellent job on the problems and tasks assigned for this class.
SE4	I think I will receive a good grade in this class.
SE5	My study skills are excellent compared with others in this class.
SE6	Compared with others in this class, I think I'm a good student.
IV1	I prefer class work that is challenging so that I can learn new things.
IV2	I like what I am learning in this class.
IV3	I think I will be able to use what I learn in this class in other classes.
IV4	Even when I do poorly in a test, I try to learn from my mistakes.
IV5	I think that what I am learning in this class is useful for me to know.
A1	I am so nervous during a test that I cannot remember the facts I have learned.
A2	I have an uneasy, upset feeling when I take a test.
A3	I worry a great deal about tests.
A4	When I take a test, I think about how poorly I am doing.
LLS1	When work is hard, I either give up or study only the easy parts.
LLS2	I often find that I have been reading for class but don't know what it is all about.
LLS3	I find that when the teacher is talking, I think of other things and don't really listen to what is being said.

LS – Learning Strategies; SE – Self-efficacy; IV – Intrinsic Value; A – Anxiety; LLS – Lack of Learning Strategies

LS3, LS4 and SE2 were removed in the further refined MSLQ with 25 items

Adopted from Liu et al. (2012) and Ng et al. (2017)

Observation, verbal reporting and interviewing protocols

Observation of students in action, verbal report by students, and interview of students are other means to elicit metacognitive related thoughts and activities. In this section, the Self-Regulated Learning Interview Schedule (SRLIS) and Think Aloud Protocol (TAP) are discussed.

Appendix C

The Self-Regulated Learning Interview Schedule (SRLIS)

The SRLIS developed by Zimmerman and Martinez-Pons (1986, 1988) is the most formalised interview measure available (Pintrich et al., 2000). Using an individual-interview format, the respondents were asked about specific tasks with follow-up probing questions in six different academic contexts (i.e., classroom discussion, short writing assignment, Mathematics assignment, end-of-term test, homework assignment, and studying at home). Students are presented with one- or two-sentence description of the context and then asked about the ways in which they would manage the situations. For instance, teachers often assign Mathematics homework to their students can ask “How do you go about doing your homework? Do you have any particular methods to help you plan and do your homework? What do you do when you encounter difficulties in completing your homework?” Responses are then coded into the following ‘14 plus 1’ categories: (1) self-evaluation, (2) organising and transforming, (3) goal-setting and planning, (4) seeking information, (5) keeping records and monitoring, (6) environmental structuring, (7) self-consequences, (8) rehearsing and memorising, (9-11) seeking social assistance from peers, teachers or adults, (12-14) viewing records from tests, notes or textbooks and (15) others. The above data could be summarised according to three different procedures: (a) strategy use, (b) strategy frequency (i.e., the number of times that a particular strategy is mentioned) and (c) strategy consistency (i.e., each strategy use is weighted by the student’s estimate of its frequency of use like ‘seldom = 1’; ‘occasionally = 2’; ‘frequently = 3’; and ‘most of the time = 4’. Zimmerman and Martinez-Pons (1986) reported that the SRLIS produced substantial correlation with students’ academic achievement with higher achieving students reporting significantly greater use of self-regulated learning strategies than their lower achieving counterparts. The higher achieving group as compared to the lower ones also reported higher use of social assistance from peers, teachers, and parents.

Appendix D

Think Aloud Protocol (TAP)

Think-aloud protocol or the TAP, is “an online method where evidence of metacognition is derived from an instruction to ‘think aloud’ while engaging in an activity, e.g., problem solving” (Gascoine et al., 2017, p. 31). In most cases, students are given a problem-solving task and asked to verbalise their thought processes to the interviewer (Garner, 1982, 1987; Paris, 1991). These processes will be recorded and coded according to the various metacognitive processes. Students will be probed to verbalise their thoughts when they go quiet. TAP requires relatively more resources in terms of time and manpower to be conducted as compared to survey questionnaires. Each student’s think aloud session would have to be recorded, transcribed verbatim, and analysed according to some form of metacognitive coding scheme. More than one coder may be needed to enhance the rigour of the method. Appended is a sample list (*see* Table D1) of the coding scheme used in a study conducted (Desoete, 2007).

The ‘online’ or synchronous nature of the thinking aloud may affect the measurement of metacognitive processes by competing for limited resources that are necessary for task performances (Schraw, 2000). To elaborate, requiring students to perform a given task and simultaneously verbalising his or her thoughts would inevitably increase the cognitive load of the students being assessed. Despite this limitation problem, this method may facilitate metacognitive behaviours by calling explicit attention to task demands.

Table D1. *Coding Scheme for TAP (Summarised Version)*

Item conceptual affiliation	**Questions**
Prediction/ Orientation	• Entirely the problem oriented on comprehension.
	• Underlining important words in the word problem.
	• Selecting the relevant information needed to solve the problem.
Planning	• Selecting relevant numbers/data to solve the problem.
	• Selecting relevant steps to solve the problem.
	• Selecting relevant materials to solve the problem.
Monitoring	• Adhering systematically to the plan.
	• Correct in calculation.
	• Makes correct use of unities and tens.
Evaluation	• Summarising the answer and reflecting on the answer.
	• Reflecting on what went well and how the tasks were solved.
	• Drawing a conclusion referring to the tasks.

There are a total of 11 questions for prediction/orientation, 6 for planning, 17 for monitoring and 5 for evaluation in the original coding scheme (*see* Desoete (2007) for the full list of coding scheme)

Appendix E

Knowledge monitoring assessment

The knowledge monitoring assessment evaluates the difference between students' estimates and their actual (determined by a performance test) knowledge or ability (Tobias & Everson, 1996). When using knowledge monitoring assessment, students are first asked to estimate their knowledge or ability to perform a task or a series of tasks. The actual knowledge or ability is then assessed by administering an objective test, usually in multiple-choice format. The difference between students' estimates and their actual knowledge are used as a measure of the accuracy of students' metacognitive knowledge monitoring abilities. Typically, this form of assessment generates four scores that indicate students' estimates and their actual test performance. The four scores, scenarios or possibilities are:

(a) student estimated knowing how to solve or do the task and answered or perform it correctly (denoted as + +)

(b) student estimated not knowing how to solve or do the task and also got it wrong (- -)

(c) student estimated knowing how to solve or do the task but got it wrong or was unable to perform the task (+ -)

(d) student estimated not knowing how to solve or do the task but got the answer right or was able to perform the task (- +)

Appendix F

Survey instrument for teachers' metacognition

Research into metacognition has revealed that teachers' metacognition can support students' learning and teachers' self-awareness is a necessary prerequisite for facilitating students' metacognition (Balcikanli, 2011; Jiang et al., 2016; Safari & Meskini, 2016). If teachers were to teach students to think in a metacognitive way, they must be metacognitive themselves, and be aware of their own metacognition. Many studies and inventories have examined students' metacognition but few have looked into teachers' metacognitive awareness. It would be necessary for teachers to be aware of their own level of metacognitive awareness if they were to facilitate their students' metacognitive awareness since teachers' metacognitive knowledge has a significant impact on his or her pedagogical understanding of metacognition. According to Wilson and Bai (2010), teachers who have a comprehensive understanding of metacognition reported that having a deep understanding of the concept of metacognition and metacognitive strategies can contribute to teaching students to be metacognitive (Wilson & Bai, 2010).

Balcikanli (2011) adapted the Metacognitive Awareness Inventory (MAI) designed by (Schraw & Dennison, 1994) and developed the Metacognitive Awareness Inventory for Teachers (MAIT) with 24 items/questions to facilitate teachers' self-awareness of their metacognitive knowledge (i.e., declarative, procedural and conditional knowledge) and metacognitive regulation (i.e., planning, monitoring and evaluating). Kallio et al. (2017) further refined and condensed the above MAIT into 18 items/questions. The authors conducted the study with 208 in-service teachers in Finland. The study's findings revealed that metacognition works not only for students but also enables teachers to improve their teaching skills (Kallio et al., 2017).

However, Jiang et al. (2016) observed that MAIT was not able to measure teacher metacognition as it excluded the metacognitive experiences component, which acted as a mediator between teaching and learning. The authors later proposed a 28-item/question survey instrument and named it the Teacher Metacognition Inventory (TMI). The TMI was originally in Chinese/Mandarin version. A copy of this was obtained from the authors and it was further refined in accordance with the items found in Jiang's published manuscript (see Table F1 for the list of items in TMI). The revised TMI in English version examined the following six factors: Teacher Metacognitive Experiences (TME), Metacognitive Knowledge about Pedagogy (MKP), Teacher Metacognitive Reflection (TMR), Metacognitive Knowledge about Self (MKS), Teacher Metacognitive Planning (TMP) and Teacher Metacognitive Monitoring (TMM).

The survey instruments, as seen in the above, could be used as self-reflective tools to investigate more in-depth metacognitive practices from teachers. These instruments help further unpack teacher metacognition into more operational and behavioural terms. Professional learning communities with knowledgeable others could provide a means for teachers to better their understanding of metacognition and its components (Prytula, 2012).

Table F1. *The Teacher Metacognitive Inventory (TMI)*

Items	**Constructs**
I am worried when my students feel bored in my class.	TME
I am worried when I am unable to control the pace of my lesson well.	TME
I feel anxious when I encounter problems in my teaching.	TME
I feel relaxed when I complete my teaching tasks.	TME
I feel happy when I created a good lesson plan.	TME
I know demonstration can make abstract concepts more concrete in learning.	MKP
I believe questioning techniques can stimulate students' thinking.	MKP
I understand that small group discussion is not suitable when lesson time is tight.	MKP
I believe interacting with students helps them to be more attentive in class.	MKP
I assess the appropriateness of the learning objectives after I taught the class.	TMR
I reflect on the lesson design of the lesson after each lesson.	TMR
I reflect on how well I meet the lesson objectives after each lesson.	TMR
I think about whether there are alternative teaching strategies after teaching a class.	TMR
I reflect on the effectiveness of the lesson after a class.	TMR
I reflect on my teaching after the lesson.	TMR

(continued)	
I evaluate the extent to which I have achieve the lesson objectives after a class.	TMR
I have a good grasp of the concept, principles, and methods of the subject(s) I teach.	MKS
I am able to prepare myself before the start of a class.	MKS
I know what are the strengths in my teaching.	MKS
I am aware of my shortcomings in teaching.	MKS
I predict and plan for possible classroom scenarios.	TMP
I set clear learning goals before each class.	TMP
I prepare and plan my lesson before teaching a class.	TMP
I pay attention to the state of my emotions when I teach.	TMM
When teaching, I frequently check whether the progress of the lesson is as planned.	TMM
When teaching, I often ask myself "how well do I teach?"	TMM
I constantly assess the feasibility of the teaching strategies I use when in class.	TMM
I constantly check students' understanding of the lesson.	TMM

Adapted from Jiang et al. (2016)

Appendix G

The Good Strategy User Model

The Good Strategy User Model is characterized by the prevalent use of (a) strategies; (b) specific strategy knowledge; (c) general meta-strategic knowledge and general strategies; (d) knowledge base; and (e) coordination of strategies and knowledge (Pressley, 1986; Pressley et al., 1987, 1989). Pressley, Borkowski, and Schneider (1989) observed that GSUs have repertoires of memory, comprehension, composition, and problem-solving skills. They also possess essential metacognitive knowledge for implementing strategies, such as knowing when and where each strategy may be useful, and the amount of cognitive effort needed for using a particular strategy Each component of the Good Strategy User Model is elaborated below.

Strategies

Fundamental to the GSU is the knowledge of strategic procedures, in particular, the goal specific strategies for accomplishing intended goals. Two types of strategies are frequently undertaken by the GSUs, namely monitoring and higher-order strategies. Monitoring strategies assess various aspects of cognition, including whether the goal-specific strategies are working in achieving their purposes. Monitoring and goal-specific strategies are conflated into sequences by (Pressley, 1986) higher-order (e.g. planning and organizing) strategies. Higher-order strategies are necessary for accomplishing complex goals that comprise a number of sub-goals where each requires a distinct cognitive strategy to solve (Pressley et al., 1987).

Specific strategy knowledge

GSUs have a repertoire of knowledge about how, when, and where to use strategies. Such knowledge is required for discriminating when to apply particular strategies and, thus, constitutes a critical part of metacognition (Pressley et al., 1984; 1985). Strategies that are accompanied by specific strategy knowledge function when particular conditions, encoded in specific strategy knowledge, are met. In the GSU model, emphasis is placed on specific strategy knowledge because it is critical to tailor cognitive processing to situational demands. Higher-order strategies assemble strategy sequences by matching the subtask requirements to specific strategy knowledge.

General metastrategic knowledge and general strategies

While monitoring, and higher-order strategies, which are goal-specific, are essential in the GSU model, Pressley (1986) argued for the relevance of general metastrategic knowledge for supporting the use of strategies. Strategies can often be generalized and, if properly matched to new situations, can produce significant improvements in performance. Such knowledge can also motivate a tendency to try to stretch strategies to fit new situations (Pressley et al., 1987). Motivation by one's uses of general knowledge, for example, can influence the uptake of general strategies and their concomitant appropriate use of specific strategies. Often, general metastrategic knowledge foregrounds the importance of personal effort as a determinant of success. From the perspective of GSUs, competing distractions, emotions, and courses of action need to be removed if strategic actions and plans are to be successful. Being able to do so renders GSUs to be high in action control (Kuhl, 1984, 1985).

Knowledge base

In the GSU model, emphasis is also placed on learners' knowledge base which contains knowledge coded in schematic, associative, categorical, and imaginal forms (as well as a few other formats) (*see* Eysenck and Wilson (1984)). Knowledge also includes both episodic information (e.g., a recount of learning to read the word 'red' on the first day in school decades ago) and the more decontextualized, semantic information (e.g., knowledge about the different shades of colour that qualify as red). This knowledge base expands readily by making inferences from episodic and semantic information, where inferences are often consistent with reality, though not always so. The knowledge base supports GSUs in three ways. First, when learning material in familiar domains, it is often assimilated to the knowledge base rather than having new strategies to learn it. Second, there is automatic coding of some material because of the congruency of the material with the knowledge base which can prompt strategy use with other materials (Pressley et al., 1987). For instance, when people learn a list with easy-to-categorize items, they organize the material by categories automatically, requiring no deliberate strategy use. Third, knowledge enables the use of many strategies. General problem-solving strategies often work when the learner possesses a lot of knowledge about the problem domain (Gagné, 1985).

Coordination of strategies and knowledge

Good strategy use is well organized and efficient. When faced with a task, the GSU is generally attentive to the task and would normally deploy effort. When the answer to a problem is already known, or when the means to communicate, in the situation, is readily apparent, GSUs do not deploy any problem-solving, memorization, or communications strategies (Pressley et al., 1987, 1989). Instead, GSUs rely on what they know. However, if the new situation lacks congruency with prior knowledge, the GSU would select specific strategies based on the matches between problem attributes and attributes coded in specific strategy knowledge that define when particular strategies are called for. If the strategy requires some world knowledge, assessment of the situation includes whether the learner has relevant nonstrategic knowledge stored away. If it is a complex task, a higher-order sequence of strategies is planned and executed.

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