Section IV

Critical thinking and metacognition
Metacognition and teaching higher order thinking (HOT) in science education

Students’ learning, teachers’ knowledge and instructional practices

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Introduction

Before participating in the teachers’ workshop, I used to address HOT in my teaching intuitively. But now I realize that doing so without explicitly addressing metacognition means that I had accomplished only a very small part of the job.

(a participant in a teachers’ professional development workshop).

Since the early days of studying metacognition, metacognitive training and instruction were shown to have positive effects on children’s performance in diverse fields. As we shall see in what follows, metacognition has both domain-general and domain-specific features. Therefore, it makes sense to study metacognition in general contexts as well as in the context of specific school disciplines and even in the context of more specific learning goals. Accordingly, the goal of this chapter is to present an overview of the role of metacognition in teaching higher order thinking (HOT) in science classrooms.

What is metacognition?

Of the numerous definitions of metacognition, we adopt, with slight adaptations, the one proposed by Flavell and his colleagues (Flavell, Miller, & Miller, 2002). These scholars distinguish between two major components of metacognition: metacognitive knowledge and metacognitive monitoring and self-regulation. The latter component is also referred to by many
researchers as metacognitive skills. A third aspect of metacognition that is mentioned by Flavell et al. is metacognitive experiences.

Metacognitive knowledge (MK) refers to knowledge, beliefs, ideas, and theories about people as “cognitive creatures” and about their diverse interactions with cognitive tasks and strategies (Flavell, 1979). MK includes three sub-categories: knowledge about persons, tasks, and strategies. In the context of teaching HOT, knowledge of tasks and strategies is particularly significant. Kuhn (1999) views strategy and task knowledge as interrelated sub-components of metastrategic knowledge. Metastrategic knowledge, as defined by Kuhn, entails knowledge about what thinking strategies can accomplish, about when, why, and how to use these strategies, and about the goals and requirements of tasks (Kuhn, 1999; Kuhn & Pearsall, 1998).

Metacognitive skills (MS) are the skills and processes used to guide, monitor, control and regulate cognition and learning. For example, Schraw and Moshman (1995) point out three essential skill categories: planning, monitoring, and evaluation. Another significant component of metacognition that had traditionally received less attention from researchers is metacognitive experiences (ME) (Efklides, 2006). Flavell and his colleagues define ME as “cognitive or affective experiences that pertain to a cognitive enterprise” (2002, p. 154).

The role of metacognition in teaching higher order thinking (HOT) in science education

We use the term HOT to delineate cognitive activities that are beyond the stage of recall and comprehension/understanding, according to Bloom’s (1956) taxonomy and according to more recent revised models (e.g., Krathwohl, 2002; Leighton, 2011). Applying, analyzing, evaluating, and creating are the key educational objectives at the HOT level. Examples of cognitive activities that are classified as HOT include constructing arguments, asking research questions, making comparisons, dealing with controversies, and establishing causal relationships (Zohar, 2004). These cognitive activities are used for carrying out processes such as scientific inquiry, problem solving, decision making, argumentation, and critical thinking.

Many methods for teaching HOT embrace metacognition as a crucial component of instruction. In order to understand the importance of metacognition in teaching HOT, let us consider a successful execution of a HOT strategy in science education, for example – variable control. When designing an experiment, students need to know that the task requires variable control, to understand why variable control should be used (e.g., that without it inferences will be invalid), and to know how to control variables (e.g., to change only one variable at a time while keeping the other variables constant). These are components of metacognitive knowledge regarding the when, why, and how of performing the strategy, or, using the terminology presented earlier, this is MSK about variable control. However, in order to actually control variables during their experimentation students also need to carefully plan their actions, to monitor their actions in order to see if things are going according to plan, and to evaluate whether they have indeed controlled variables correctly and if their inferences are valid. This evaluation may lead the students to conclude that they need to design a new and better experiment. That is, successful execution of a HOT strategy also requires MS such as planning, monitoring, evaluating, and regulating. In the next sections we will take a deeper look at why MSK and MS are so important for competent and efficient HOT.

The contribution of metastrategic knowledge (MSK) to higher-order thinking

The significance of MSK in learning to think is based upon the observation that children at any given time hold a variety of thinking strategies that they use with different relative frequencies (Kuhn, 2000a; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Siegler, 1996). Therefore,
development is seen as the increasing ability to choose effective strategies from a large repertoire of strategies with varying degrees of effectiveness. According to Kuhn (1999, 2000b), it is at this point that MSK becomes important, because it is a necessary factor in the increasing ability to choose more accurate strategies.

The claim that increasing students’ MSK enhances strategic thinking implies that it may be fruitful to try and teach that knowledge rather than wait until it develops spontaneously. Addressing MSK in the classroom often amounts to helping students see the general thinking structures embedded in the “messy” domain-specific situations they are dealing with. For instance, students may not see any connection between an inquiry activity they are doing in class in the subject of seed germination and an inquiry activity they did a month earlier in the topic of force and motion. The teacher, however, can explicitly point out that both activities share the same features of the inquiry cycle and that the rule they had learned regarding the need to control variables applies in both cases. Using explicit general knowledge pertaining to MSK in teaching thinking is therefore a type of “bridging” activity that may enhance transfer (Adey and Shayer, 1993).

The contribution of metacognitive skills (MS) to higher-order thinking

In order to control and regulate their thinking, learners’ employ MS that draw on their MK regarding cognitive processes (Schraw & Moshman, 1995). MS can be viewed as the procedural or executive component of metacognition (Brown, 1987; Paris & Winograd, 1990; Veenman, 2005). MS are critical for managing thinking processes and provide the link between meta-level knowledge of strategies and tasks and cognitive performance (Borkowski, Chan, & Muthukrishna, 2000; Schraw, 1998; Veenman, 2011). For example, learners need to plan which HOT strategy to use, based on task demands, and then to monitor and regulate the use of that strategy.

Current evidence suggests that although MS have both domain-general and domain-specific aspects, they are predominantly domain-general (Schraw, Dunkle, Bendixen, & Roedel, 1995; Veenman, 2011). Developmental studies indicated that after the age of 15 metacognitive skills are largely general (Van der Stel & Veenman, 2010, 2013; Veenman & Spaans, 2005; Veenman, Wilhelm, & Beishuizen, 2004). The domain-general aspects of metacognitive skills suggest that they might more readily transfer to new tasks and domains. However, MS development occurs gradually and some learners may not spontaneously acquire competent MS (Brown & DeLoache, 1978; Veenman, Kok, & Blöte, 2005). Veenman (2011) pointed out that those learners who have metacognitive skills at their disposal but fail to produce them appropriately can be assisted by cues and reminders. But learners who do not have available MS may not equally benefit from cues and reminders. Learners with such “availability deficiencies” need to be instructed in employing MS in order to effectively acquire them (Veenman, 2011). Veenman refers to the informed instruction of metacognitive skills using the WWW and H rule: “meaning that learners should be instructed, modeled and trained when to apply what skills, why and how in the context of a task” (2011, p. 210). That is, MK about MS plays an important part in the acquisition of MS. This call brings us full circle back to the importance of MSK in promoting HOT by proposing that learners may benefit from MSK not only about HOT strategies but also about the MS required for successfully executing these strategies.

Teachers’ knowledge regarding metacognition has unique characteristics

It is not easy for teachers to take up research-based ideas about metacognition and translate them into practical classroom recommendations (Leat & Lin, 2003). This challenge is particularly large in the area of teaching HOT and metacognition. Like in any other field, in order to teach successfully teachers need familiarity of whatever it is they attempt to teach as well as
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sound knowledge of how to teach it. HOT and metacognition have both domain-specific and
domain-general features. Therefore, neither the term pedagogical content knowledge (PCK)
that is subject-specific (Wilson, Shulman, & Richert, 1987), nor the term general pedagogical
knowledge that is domain-general, are appropriate to describe teachers’ knowledge in this area.
In order to delineate the unique nature of HOT and metacognition, Zohar (2004, 2008) thus
suggested that teachers’ knowledge in this context can be addressed using the terms: “knowledge
of elements of HOT and/or metacognition” and “pedagogical knowledge in the context of
teaching HOT and/or metacognition.” These terms highlight the fact that teachers’ knowledge
in this field has unique characteristics (for a more detailed explanation see Zohar 2004, 2008).

**Teachers’ knowledge of elements of metacognition for fostering HOT**

In order to use metacognition successfully when teaching HOT, teachers need robust knowl-
dge of elements of metacognition, that is, of the pertinent metacognitive knowledge and skills
related to HOT (e.g., Seraphin, Philippoff, Kaupp, & Vallin, 2012; Zohar, 2006). A pre-condi-
tion for teachers’ metacognitive knowledge in this area is their familiarity with thinking strat-
egies and processes on the cognitive level. Research shows that teachers are not always proficient
with this knowledge (Zohar, 2004). Moreover, the domain-specific aspects of MSK suggest that
teachers may need diverse types of MSK for the diverse thinking strategies they would address in
class. Teachers obviously also need to be proficient with the MS that are relevant for planning,
monitoring, evaluating, and regulating thinking processes in the area of HOT. Such complex
knowledge of metacognition is a pre-condition for sound pedagogical knowledge in this area.
Indeed, research suggests that knowledge of metacognition and pedagogical knowledge in the
context of teaching metacognition are related to each other (Wilson & Bai, 2010).

**Teachers’ pedagogical knowledge in the context of teaching metacognition for fostering HOT**

Teachers’ pedagogical knowledge in the context of teaching metacognition for fostering HOT
should include underlying principles and instructional practices for teaching metacognition. In
this section, we will present four key underlying principles, as well as point to examples of their
connections with particular instructional practices A more systematic review of instructional
practices that emerge from empirical studies is described on pages 236–237.

**Principle #1 – deliberate attention to general thinking structures and skills**

As they engage with a variety of specific topics that are often “messy” in terms of their rich sci-
ence contents, teachers need to be able to clearly maintain in their minds the relevant general
thinking structures (e.g., MSK and MS). Such awareness contributes to teachers’ ability to treat
metacognition in the classroom in an intentional and planned way, rather than intuitively. It is
also a pre-requisite for fostering an explicit awareness of metacognition (see below). The main
teaching practice based on this principle refers to the design of lessons or even larger teaching
units. It enables teachers not to think exclusively about content goals, but to also include meta-
cognitive goals and activities in their lessons and assessments in a deliberate way.

**Principle #2 – fostering explicit awareness of metacognition**

Although when metacognition develops spontaneously it may be either implicit or explicit
(Schraw & Moshman, 1995), it is always explicit when addressed during instruction and has a
strong verbal component. Fostering metacognition requires students’ explicit awareness of the type of cognitive and metacognitive procedures being used (Zohar & Ben David, 2008; Zohar & Peled, 2008). Making metacognition explicit helps make learners’ thinking visible, an object for reflection, discussion, and evaluation (Ritchhart, Church, & Morrison, 2011). In terms of teaching practices, the construction of MSK regarding HOT can be mediated by explicit discussion of the generalizations and rules that are relevant to a thinking strategy, by naming the thinking strategy, by discussing explanations as to when, why, and how the thinking strategy should be used, and by discussing what task characteristics call for the use of the strategy. Teachers therefore need to be proficient in the “language of thinking” (i.e., vocabulary terms such as “argument,” “reason,” or “conclusion”) in order to introduce metacognition routinely into classroom discourse (Swartz et al., 2008; Tishman, Perkins, & Jay, 1995). Similarly, MS can be acquired by explicit discussion of the MS that are relevant to the performance of science learning strategies and tasks, by naming the MS, and by discussing explanations as to what, when and how MS need to be used.

**Principle #3 – teaching in a meaningful way**

It is important to note that although we promote explicit instruction of metacognition, this does not mean that metacognition should be taught through a “transmission of knowledge” approach. Our general educational belief is that knowledge must be actively constructed by knowers in order to be meaningful. This belief extends not only to the learning of concepts and strategies (Zohar, 2004) but also to the learning of HOT and metacognition. Thus, the explicit teaching of metacognition should be designed to trigger and facilitate active thinking and experiences that fosters deep understanding. In fact, resourceful metacognitive teaching requires teachers’ understanding of both social and personal processes of knowledge construction. The social exchange of ideas encourages learners to expand, challenge, and deepen their understandings (e.g., Molenaar, van Boxtel, & Sleegers, 2010). Furthermore, recent studies suggest that there are important connections between individual and socially shared aspects of metacognitive regulation (Efklides, 2008; Grau & Whitebread, 2012). Social aspects of metacognitive learning can include student-led small group discussions, teacher-led whole class discussions, scaffolding and modeling.

Because metacognitive knowledge about HOT strategies and about MS is highly abstract, it is unlikely that most students will be able to understand it deeply without engaging in an extended series of practical experiences. In this sense, addressing rules, generalizations and principles of good thinking always needs to be connected to students’ concrete experiences in which they use thinking strategies and metacognitive skills. The teaching practices of cueing and prompting learners during the task are often necessary in order to remind learners to activate their MK and MS and in order to help them connect their understandings and skills to the current context. Providing practice and training also offers learners opportunities to acquire first-hand experience with metacognitive thinking. This might also be achieved through reflective writing and through visual representations that assist students in exposing, transforming, and communicating their thinking.

**Principle #4 – thinking across and beyond specific contexts**

As mentioned earlier, metacognition has both context-specific and context-general aspects. This introduces a serious challenge to educators since they need to pay attention to domain, task, and strategy specific aspects of metacognition as well as to assist learners in forming generalizations that will enable them to extend their metacognitive knowledge and skills to new contexts.
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We would claim that when teaching HOT this challenge is greater in the case of MSK than in the case of MS. MSK relates to specific tasks and thinking strategies and it has a considerable degree of context-dependence. Consequently, it needs to be taught separately for each type of thinking. This creates considerable challenges in the classroom because unique learning activities need to be designed for the teaching of each type of thinking (e.g., the knowledge relevant to teaching how to construct good arguments is very different from the knowledge of teaching how to control variables or how to ask good research questions). Yet, MSK and MS also have general aspects. For instance, MSK regarding argumentation that is taught in the context of a dilemma in human genetics would also apply to an environmental dilemma.

In light of these considerations, teachers need to know how to use metacognition to enhance transfer by “bridging” or “transfer” activities designed to highlight the underlying common thinking elements embedded in multiple specific cases (Adye & Shayer, 1993; Swartz et al., 2008; Tishman et al., 1995; Zohar, 2006). In terms of teaching practices, using metacognition for bridging (or transfer) can be accomplished in several ways: (a) After explicitly discussing the general characteristics of a thinking strategy, a thinking task or a metacognitive strategy, teachers can explicitly ask students to raise additional instances (both school-related instances and instances from everyday life) in which the same kind of thinking can be applied. (b) When a thinking strategy or a metacognitive skill that had been learned in the past is embedded once again in the course of teaching a new subject, teachers can point out (or ask students to point out) the general meta-elements that are common to the new and old cases. (c) In order for such activities to be effective they need to recur in multiple contexts over extended periods of time. Therefore, a third significant teaching practice for transfer is long-term and systematic planning of large units of instruction that will provide students with opportunities to encounter the same metacognitive principles in multiple science contents. (d) A fourth teaching practice may involve using similar structured checklists and prompts repeatedly in multiple science contexts (see, for example, Kramarski & Mevarech, 2003; Schraw, 1998).

Research about teachers’ knowledge

To what extent are teachers in fact familiar with knowledge of metacognition and with principles and practices of metacognitive instruction? Veenman et al. warned that many teachers lack sufficient knowledge of metacognition and of how to use metacognition in their teaching (Veenman, Van Hout-Wolters, & Aflerbach, 2006). These findings are confirmed by several studies documenting science teachers’ lack of adequate knowledge about metacognition and its teaching (e.g., Ben-David & Orion, 2012; Seraphin et al., 2012; Zohar, 2006). Therefore, research findings indicate that a serious gap exists between research-based recommendations and the actual state of teachers’ knowledge in this area. Because teachers’ knowledge is a pre-requisite for classroom practice, this gap is also reflected in actual classroom practice (Georghiades, 2004; Thomas, 2012).

An overview of research on metacognition in science education

In order to examine how metacognition is currently conceptualized and studied in the field of science education we have recently conducted a systematic analysis of 178 studies on metacognition and science education published in peer-reviewed journals in the years 2000–2012 and indexed in the ERIC database (Zohar & Barzilai, 2013). The review revealed several major trends:
• There has been a dramatic growth in the volume of research throughout the past decade.
• Metacognition is mostly studied in disciplinary contexts and is well-integrated in core objectives of science education.
• Metacognition is studied more among older students than among younger ones.
• Teachers’ knowledge about metacognitive instruction is under-researched.

How important and central is research concerning metacognition and HOT in science education? We re-examined the corpus of studies and found that many of them addressed HOT skills and processes such as: general thinking skills (e.g., reasoning) (23.6% out of 178 studies); problem solving (22.5%); inquiry learning (21.9%); specific thinking skills (e.g., variable control) (15.2%); problem-based learning (5.1%); argumentation (3.9%); critical thinking (3.4%); scientific thinking (2.8%); and thinking dispositions (2.8%). This list indicates that metacognition is studied in relation to multiple and varied aspects of HOT. Taken together, 51.1 percent of the studies of metacognition in science education that were indexed in ERIC between 2000 and 2012 are related to HOT. We may, therefore, conclude that HOT is one of the central educational issues that interest researchers of metacognition in science education.

Papers in which metacognition played a central role were chosen for a deeper analysis. Of the 66 studies chosen for deep analysis, 24 focused specifically on HOT. Our next analysis addressed two questions: Which metacognitive aspects are being studied? What types of instructional approaches are used to foster learners’ metacognition? We found that studies of metacognition in science education largely address the two major components of metacognitive knowledge and metacognitive skills. However, we were somewhat surprised to find that metacognitive skills were studied much more often than metacognitive knowledge (86.4% versus 37.9% among all studies, 83.3% versus 50.0% in the HOT studies). It is interesting to note that all of the HOT studies that addressed learner’s MK specifically targeted MSK. This provides another indication of the centrality of MSK in HOT instruction. Metacognitive Experiences (ME) were rarely addressed in the studies we reviewed.

The studies revealed a rich repertoire of instructional practices for engaging learners in metacognitive thinking. Figure 19.1 provides the frequencies of the metacognitive instructional practices employed in all studies and in the HOT studies and examines the relations between the metacognitive components studied (MK and MS) and the instructional practices employed. In the next paragraphs we provide an overview of these practices, specifically focusing on their relevance to the teaching of HOT:

- **Metacognitive prompts** – The most frequently recurring metacognitive instructional practice was use of metacognitive prompts. These prompts were metacognitive cues, questions, or checklists that students were asked to use during activities such as problem solving and inquiry learning, in order to remind them to utilize metacognitive skills. Alternatively, they were used to support the activation of metacognitive knowledge regarding HOT strategies (e.g., Fund, 2007; Peters & Kitsantas, 2010). These prompts were also used as scaffolds in group and class discussions, in written assignments, and in inquiry software.

- **Explicit instruction** – This category included practices whose goal was to visibly and explicitly teach metacognitive knowledge or metacognitive skills. In HOT studies, explicit instruction took on multiple forms, such as explanations and demonstrations by the teacher regarding HOT (e.g., Duncan & Arthurs, 2012; Zohar, 2006), knowledge construction activities which require learners to build their metacognitive understandings of HOT (e.g., Ben-David & Zohar, 2009; Kaberman & Dori, 2009), and learning materials that offer models and explanations regarding HOT.
Metacognitive instructional practices in all studies (n = 66)

Metacognitive instructional practices in HOT studies (n = 24)

Figure 19.1 Recurring metacognitive instructional practices: a comparison of the practices used for fostering metacognitive knowledge and metacognitive skills.

Note: Studies could appear in more than one category. The percentages represent the proportion of studies that used each instructional practice within each of the two metacognitive categories (i.e., MK and MS).
• **Practice and training** – Following instruction, learners were sometimes asked to apply and practice what they learned as they solved various problems and tasks. The pertinent studies provided learners with opportunities for activating and applying their metacognitive knowledge and skills over prolonged periods of time and in extended contexts.

• **Metacognitive discussions** – Whole class and group discussions of HOT provided opportunities for students to articulate the cognitive and metacognitive processes they apply. In teacher-led discussions teachers talked with their students about their thinking in order to make it visible, thereby supporting learners’ developing understandings of their thinking (e.g., Wu & Pedersen, 2011). Student-led discussions were conducted in structured or semi-structured ways which were intended to facilitate metacognitive talk among peers. These discussions were scaffolded using cues and prompts that evoke cognitive and metacognitive processes (e.g., Peters & Kitsantas, 2010) or analysis of scenarios and case studies (e.g., Conner, 2007; Zohar, 2006).

• **Reflective writing** – These practices included writing of journals, responses to metacognitive questions, reports, or short reflections in which learners have opportunities to reflect on, describe, and analyze their thinking in writing. For example, learners wrote diaries or journals about their thinking and learning (e.g., Nielsen, Nashon, & Anderson, 2009) reflective essays (e.g., Kipnis & Hofstein, 2008), or short written responses to reflective prompts (e.g., Lewis et al., 2011; Morgan & Brooks, 2012).

• **Visual representations** – We also found studies which employed visual representations in order to help learners and teachers represent and share their thinking, such as graphs that helped students monitor their scientific inquiry strategies (Peters & Kitsantas, 2010) or a diagram of an inquiry process that helped teachers form connections between metacognitive inquiry activities and the inquiry cycle (Seraphin et al., 2012).

• **Metacognitive modeling** – Metacognitive modeling entails activities in which the teacher demonstrates how she or he activates and applies metacognitive knowledge and skills in order to scaffold these practices for students. We found several studies in which teachers or animated computerized agents were used to model thinking and comprehension strategies (e.g., Ben-David & Orion, 2012; Graesser, McNamara, & VanLehn, 2005).

• **ICT use for metacognitive instruction** – We found that information and communication technologies (ICT) were predominantly used in order to provide metacognitive scaffolds that support activation of HOT strategies, monitoring, and reflection during computer-based inquiry learning (e.g., Fund, 2007; Graesser et al., 2005; Zhang, Chen, Sun, & Reid, 2004).

As can be seen in Figure 19.1, the component of metacognition employed for fostering HOT (MK or MS) and the metacognitive instructional practices are sometimes related. Notably, metacognitive prompts were more frequently employed in studies that address learners’ MS than in studies that address MK (in all studies, $\chi^2 (1, N = 55) = 6.66, p = .010$, in HOT studies, $\chi^2 (1, N = 32) = 3.14, p = .076$). Explicit instruction recurred more often when MK was taught than when MS were taught (in all studies, $\chi^2 (1, N = 55) = 5.24, p = .022$, in HOT studies, $\chi^2 (1, N = 32) = 3.69, p = .055$).

**Studies addressing teachers’ knowledge and PD**

Only five out of the 178 (2.8%) studies in the corpus we analyzed had addressed teachers’ knowledge and PD in the area of teaching metacognition. Interestingly, four of these studies were in the area of teaching HOT. Those studies showed that teachers’ intuitive knowledge of metacognition
(i.e., before encountering metacognition during PD) in the context of teaching HOT is quite poor, that it can be developed through PD, but that in order to be effective such PD needs to be relatively lengthy and requires subsequent long-term support (Ben-David & Orion, 2012; Greenleaf et al., 2011; Seraphin et al., 2012; Zohar, 2006).

Examples of successful metacognitive instruction

In this section we analyze in some detail two examples of successful instructional programs for fostering metacognition and HOT. The examples were chosen because they demonstrate how the instructional principles and practices, described above, can be effectively employed in authentic classroom instruction in order to foster both MK and MS.

The ThinkerTools Inquiry Curriculum

In the computer-enhanced ThinkerTools Inquiry Curriculum, White and Frederiksen (1998, 2000) aimed to teach scientific inquiry and modeling in the context of teaching force and motion. Metacognitive knowledge was taught as the steps of the Inquiry Cycle (question, predict, experiment, model, and apply) were explicitly presented to students. The meta-level knowledge presented to students about the steps of the Inquiry Cycle corresponds well with our previous definition of MSK. Metacognitive skills were taught through a reflective self-assessment process in which prompts directed students to monitor, reflect, and evaluate their own and each other’s research. This process employed a carefully chosen set of explicit metacognitive criteria such as “being systematic,” “understanding the process of science,” and “reasoning carefully.”

White and Frederiksen employed many of the metacognitive instructional practices mentioned throughout this chapter. In addition to metacognitive prompts, metacognitive knowledge of the various stages of the inquiry cycle was explicitly taught. Rather than simply presenting the relevant information, deep understanding of the nature and purpose of the inquiry stages was developed by a set of scaffolded activities that guided students as they actively engaged in real-world experiments. Students’ understanding was further expanded and deepened as they talked about, evaluated, and reflected on the characteristics of each inquiry step. Practice and training were provided in the form of repeated inquiry cycles; Reflective writing took place as students were repeatedly required to answer in writing metacognitive questions (that included the need to criticize their work); Metacognitive discussions took place as both small groups and the whole class were engaged in intense discourse about the various metacognitive components of their work. This combination of talking and writing about MK and MS while using them during repeated practice demonstrates the mutual dependence between the growth of metacognitive knowledge and metacognitive skills. White and Frederiksen’s evaluation of their approach included carefully designed controlled experiments to determine the impact of their curriculum. Overall, students’ performance improved significantly on both physics knowledge and inquiry assessments. The curriculum was particularly beneficial for low-achieving students.

Explicit construction of MSK

The second example demonstrates how explicit teaching of MSK can be designed to help learners construct deep understanding of thinking strategies such as controlling variables, asking research questions and formulating hypotheses (Ben-David & Zohar, 2009; Zohar & Ben David, 2008; Zohar & Peled, 2008). In order to achieve this goal, Zohar and her colleagues used guided discovery, originally designed to teach science concepts, for teaching meta-level knowledge of thinking
strategies. For instance, in the case of variable control (COV), instruction started by creating a cognitive conflict between students’ initial pre-instructional faulty reasoning strategies and formal thinking strategy. This was followed by a 45-minute teacher-centered lesson with a variety of instructional means such as demonstrations, using examples from everyday life, building on students’ intuitive knowledge and classroom discourse. Using a set of leading questions, the teacher actually led students to think about, construct and articulate various aspects of the MSK pertaining to the COV strategy. This intervention was followed by several lessons in which students’ engaged (individually and in small groups) with a computer simulation that requested them to actively use the COV strategy in a variety of circumstances, thereby providing practice and training. A set of written probes, as well as teacher’s questions to individual students who failed to control variables reminded students during numerous points of their experimentation to apply metacognitive skills such as monitoring and evaluating their work (e.g., “Do you think that you are using the rule that we had studied in the previous lesson?”) and regulating their thinking (“What can you do to improve your current investigation?”). This example demonstrates once again how the metacognitive learning environment integrates explicit instruction with metacognitive prompts, practice and training, reflective writing and metacognitive discussions. In this learning environment, MSK was used to improve MS and MS were used to consolidate MSK. A set of controlled studies designed to evaluate this instructional approach showed dramatic developments in students’ strategic and metastrategic thinking following instruction. The effect of the treatment was particularly large for low-achieving students and was preserved in delayed transfer tests.

Conclusions and implications

There is strong evidence that successful HOT in science education requires both metacognitive knowledge and metacognitive skills. Nevertheless, the findings from our review point to several areas of missed potential. First, despite the theoretical and evidence-based significance of MSK for teaching HOT, this knowledge was addressed in only 50% of the HOT studies in which metacognition had a central role. Metacognitive experiences were only addressed in one study. These findings imply that researchers, and probably also practitioners, may not be paying enough attention to all the metacognitive components which can potentially improve students’ strategic and metacognitive thinking. Future studies may, therefore, benefit from a more comprehensive inclusion of the various metacognitive components, in particular MSK.

It is, of course, theoretically possible that not all metacognitive components have an equal contribution to the goal of improving students’ thinking and therefore should not be addressed equally in future studies. However, the choice of which components should be addressed in metacognitive interventions needs to be evidence-based. Future studies may, therefore, aim to compare the effectiveness of addressing various metacognitive components in teaching HOT in diverse educational contexts in order to enable researchers to make informed decisions as to which metacognitive components they should use.

The findings also show that metacognitive prompts were more frequently employed in studies that address learners’ MS than in studies that address MK, and that explicit instruction recurred more often when MK was taught than when MS were instructed. As Veenman (2011) noted, cueing and prompting metacognition may remind learners to activate metacognition but cannot compensate for deficiencies in metacognitive knowledge or skills. Learners who do not have appropriate metacognitive knowledge about thinking strategies and/or about metacognitive skills at their disposal, need to be explicitly informed and instructed regarding the why, what, when, and how of using both HOT strategies (i.e., MSK) and MS (Veenman, 2011; Zohar & Ben David, 2008, 2009). It seems that studies of MS that create opportunities for metacognitive
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reflection through the use of prompts, reflective writing, or collaborative learning, sometimes fall short by not combining explicit, informed instruction, thereby missing an opportunity to construct robust and generative understandings of HOT and of metacognition. On the other hand, explicit teaching of MSK sometimes lacks the opportunity to make that knowledge more useful by combining it with prompts and cues embedded in practice and training.

In sum, the main implications of these findings are that MK and ME need to be used more often in metacognitive studies aiming to foster students’ HOT, that MS need to be taught explicitly more often, and that acquisition of MK requires more training, prompting and cueing.

Finally, this chapter, which focuses on HOT, supports conclusions from previous studies, conducted in additional areas of teaching metacognition (Georghiades, 2004; Thomas, 2012), that have highlighted a concerning theory-practice gap in relation to teachers’ knowledge and professional development. Charting the complex knowledge required for utilizing metacognition for teaching HOT against (a) the considerable gaps in relevant teachers’ knowledge found in the studies we reviewed; and, (b) the scarcity of research about how to foster teachers’ knowledge in this area, reveals a worrying state of affairs. What makes this picture even more troublesome is the fact that teachers’ pedagogical knowledge in the context of teaching metacognition must be based on constructivist theories, so that it can go beyond the transmission of instructional strategies and techniques (Van Driel & Berry, 2012). Professional development in this area must go beyond training teachers in metacognitive practices to include deep understanding of knowledge of metacognition for fostering HOT and of the teaching principles described above. Because research about how to address these issues in professional development is practically at its infancy, future studies should focus on these issues in a systematic and profound way.

References


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