



Christian Perspectives in Education

Send out your light and your truth! Let them guide me. Psalm 43:3

Volume 4 | Issue 2

5-21-2011

Do Metacognitive Strategies Improve Student Achievement in Secondary Science Classrooms?

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Recommended Citation

Fouché, Jaunine and Lamport, Ph.D., Mark A. (2011) "Do Metacognitive Strategies Improve Student Achievement in Secondary Science Classrooms?," *Christian Perspectives in Education*, 4(2).

Available at: <http://digitalcommons.liberty.edu/cpe/vol4/iss2/4>

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Do Metacognitive Strategies Improve Student Achievement in Secondary Science Classrooms?: The Case for Metacognition as Enhancement Classroom Method in the Sciences

Introduction

Metacognition is the orchestration of implementing, monitoring, and reflecting on one's thinking (Bransford, Sherwood, Vye & Rieser, 1986; Glaser, 1984). The use of metacognition, for the context and focus of this article, facilitates a framework from which meaningful discourse can more fully occur in secondary science classrooms. The authors contend that when students *and* teachers engage in the components and practices of metacognition that there is a greater likelihood that concept transfer to discrete and novel learning will occur. Further, the authors suggest that making metacognitive processes more intentional will allow for more purposeful and strategic applications (Borkowski, 1992; Weinert, 1987).

If the above assertions can be verified, and the authors believe they can, this would be a boost for science education, which continues to languish in comparison with its status in other nations. In what specific ways might metacognitive strategies boost science education? Simply put, critical thinking skills, problem-solving abilities, scientific reading comprehension, and vocabulary achievement are correlated with metacognitive strategies of teaching. With the increase in high-stakes standardized testing and the growing importance of scientific inquiry and problem-solving skills, increasing students' abilities for cognition and metacognition have become even more relevant. Research supports the notion that metacognitive strategies, when used effectively, result in increased learning and achievement (August, Flavell & Clift, 1984; Bransford, Brown & Cocking, 2000; Everson, & Tobias, 1998; Jones & Idol, 1990). For example, instruction in metacognitive strategies enhances reading comprehension and vocabulary achievement of third-grade students (Boulware-Gooden, Carreker, Thornhill & Joshi,

2007; Fisher, 1998; Salmon, 2008) and fourth- and fifth grade students (Pressley, Wharton-McDonald, Mistretta-Hampton & Echevarria, 1998).

Herein, the authors attempt to address the critical intersection between metacognitive strategies and the secondary science classroom, and key differences between novice and expert learners. Finally, the article considers the roles of teachers and students in the classroom, the importance of classroom culture and structure, and the potential impact of improved metacognition on assessment.

But first, how might Christians view knowledge and learning?

A Christian Perspective on Knowledge and Learning

Christians search for knowledge, understanding, and wisdom (Waltke, 2005). The wisdom book of Proverbs speaks eloquently of these worthy attainments. Proverbs 12:1 claims, “Whoever loves instruction loves knowledge...” In addition, Christians are to provide other Christians, and others who would hear it, with wise instruction. Proverbs 11:14 warns, “Where there is no counsel, the people fall; but in the multitude of counselors there is safety.” Proverbs 9:8-9 says, “Rebuke a wise man, and he will love you. Give instruction to a wise man, and he will be still wiser; teach a just man, and he will increase in learning.” So, in sum, not only are followers of God to be open to receiving wisdom, but Christians are also to share it willingly with those who would hear it (Lamport & Yoder, 2006).

In the same vein, educators also have a responsibility to surround their students with opportunities to gain and share knowledge, understanding, and wisdom about the natural world. Too long have faith and science been viewed as incongruous. Neither has anything to fear from the other – God is the author of all truth. Christian educators, although they provide students with content-specific learning opportunities, intend that many of the underlying skills they teach be

carried outside of the school walls and applied to a student's life in general. The broadest purpose of education is to provide students with a content *and* skill base sufficient so that they are able to be productive and upright citizens, both of one's geo-political nation and real but scattered kingdom of God on earth (Lamport & Yoder, 2006).

Much of the higher-level learning in which students engage requires them to use metacognitive skills. However, students are often not aware of their own thinking, let alone how to use their thinking to change their academic, social, or even spiritual lives. This concept of reflecting on one's thoughts was practiced by the first-century Apostle Paul, a teacher in his own right, with the converts and followers in his numerous new congregations. Paul provided the example of examining his thoughts and then acting on them to make changes. In Romans Chapter 7, Paul attempts to explain his internal struggle with sin: a poignant conflict as he seeks to bring about submission of his mind to God. For Paul to make a change, he needed first to *be aware* that his thoughts were contrary to the will of God. He also needed then *do something* about it, i.e., to take action to make a change. Paul instructs believers to “demolish arguments and every pretension that sets itself up against the knowledge of God, and we take captive every thought to make it obedient to Christ” (2 Corinthians 10:5, *NIV*). In much the same way, teachers ask students not only to become aware of their thoughts, but also to understand them and take steps to change their thoughts so that they are more productive and effective. Teachers do this not only through modeling for their students, which is a very powerful strategy nonetheless, but also by providing opportunities for students to share and practice with each other.

What then is a proper understanding of the concept of “intelligence,” and what necessarily distinguishes cognitive from metacognitive processes? An overview follows.

A Metacognitive Snapshot

Experts once thought that intelligence was fixed, that one was born with all the aptitude one would ever have. However, a growing body of studies suggests that this may not be the case at all (Costa, 2008; Dweck, 2006; Whimbey, 1975). This research supports the notion that intelligence, with proper input and motivation, can not only grow but also endure. Along with intelligence research, research on metacognition has supported the notion that the ability to “think deliberately about our thinking” can also be taught (Alter, Oppenheimer, Epley & Eyre, 2007; Bransford, Brown & Cocking, 2000; Case, 2002; Hartman, 2001).

Cognitive and metacognitive processes are intertwined and their functions are not easily distinguished. Hartman (2001a) provides an excellent analogy that explains the most salient differences between them. She likens cognition to a “worker” and metacognition to a “boss.” The worker performs the skills the boss decides are necessary. Worker strategies refer to skills such as encoding, inferring, comparing, and analyzing. Boss strategies refer to skills such as planning, monitoring, and evaluating.

The work of Flavell (1979), a seminal researcher in metacognition, is described in an article by Cooper (1999). For Flavell, metacognition is not always conscious, but is also sometimes done unconsciously. Flavell develops a four-pronged model of metacognitive monitoring: metacognitive knowledge; metacognitive experiences; tasks and goals; and strategies or actions. *Metacognitive knowledge* occurs when someone first contemplates engaging in a task. They may ask themselves what the task involves, what strategies could be used to complete the task, and whether or not they are capable of carrying it out. This can happen consciously or unconsciously depending upon the learner's *metacognitive experiences*. The more difficult the task is perceived to be, the more likely the learner will engage in deeper

cognitive processes; *or*, depending on interest level and level of motivation, the learner will disengage from the task or use surface processes simply to get through the task. This implies a level of control over these processes.

Learners' decisions to apply either deep or surface-level metacognitive strategies depend on the *tasks and goals* they are trying to achieve. What do they want as an outcome? Do they want to improve their own learning? Do they want to develop a product? Do they want simply to memorize something? The goal also influences the *actions* learners take and the strategies they use to accomplish them.

Flavell's (1987) research explores the development of metacognition in education as it relates to children. He promotes the idea that as children develop a sense of self and self-efficacy, they are more likely to feel they are capable of taking control of and influencing their own learning.

The idea of metacognition is based in cognitive psychology and its roots are most often attributed to the works of Piaget (1973) and Vygotsky (1978), although each has a slightly different view of metacognition. Piaget noted that cognitive processes develop over time and in stages. He further posits that metacognition cannot develop until approximately the age of 11, a time when most children enter the formal operational stage and are capable of thought that is more abstract. During this time, Piaget says thinking becomes intentional. In other words, it becomes planful and purposeful. Vygotsky believes that rather than one's developmental level determining his or her metacognitive prowess, social and cultural influences were the biggest predictors. He also asserts that metacognition is a deliberate and verbal action. Vygotsky's "zone of proximal development" presents a distinction between what a learner is able to do on his or her own versus with help. A balance is then reached between providing too much and not

enough assistance. Vygotsky (1978) indicates as students are able to manage these processes more on their own, they are able to move away from the help of the teacher and become more self-sufficient, an important step in metacognitive development.

Novice and Expert Learners

Research identifies several stark differences between novice and expert learners (Bransford et al., 2000; deGroot, 1965; Dweck, 2006). Bransford et al. (2000) indicate that due to the large amount of background knowledge that experts possess, they are able to see problems as they relate to the bigger picture and to the patterns that connect them. So-called “expert learners” are planners and organize their learning environments so it makes sense to them. For example, in a 1987 study by Larkin and Simon, physics experts tend to make diagrams that relate the big ideas of physics to the problem they are trying to solve. In short, experts know how to use their existing knowledge to attack novel problems and can re-organize problems to suit their vision of how it should be solved. Further, expert learners monitor their own learning and are willing to abandon a strategy that is not working in favor of one that will. In addition, they are able to chunk information so that retrieval is streamlined, placing fewer demands on their working memory.

So-called “novice learners,” on the other hand, live in the moment. Instead of looking for patterns and deeper connections, they take a surface approach, looking to solve the problem and move on. Having less to work with should mean that novices work more slowly than experts, but Bransford et al. say this is not the case. Because novices are not concerned with connections (or how their prior knowledge may or may not fit the problem), they are likely to finish with the problem quickly. Likewise, novices are not concerned with the future. They do not use feedback to adjust their learning and tend to take a passive role in the learning process.

Both expert and novice learners possess particular beliefs, or mental models, about knowledge and aptitude. In *Mindset: The New Psychology of Success*, Dweck (2006) calls these beliefs “mindsets.” She explains that aptitude is often thought of in two ways: *fixed*, the belief that one is born with all the intelligence he will ever have and that it cannot change; and *fluid*, the belief that one can change his aptitude based on one’s experiences and what is done with them. Two other prominent researchers in this field, Costa and Kalick (2008), have written about these mental models which they refer to as “habits of mind.” These habits determine whether an individual perceives themselves as in control of their learning or not. Based on this information, a person’s willingness to learn and engage in metacognitive strategies is not so much linked to aptitude or experience, but rather *attitude*.

Secondary Science Classroom Metacognition Strategies

Following are several strategies the authors contend are effective for facilitating the instruction of metacognition as applied specifically to the science classroom: cooperative learning; discussion; reciprocal teaching; probing/questioning; feedback; visual images, concept maps, graphic organizers and vee diagrams; strategic reading; and scaffolding. These strategies may not have originated in science education; however, all of them have the potential to improve secondary science education practice.

Slavin (1980) argues that cooperative learning helps to boost the use of metacognitive strategies. Placing students in cooperative groups enabled them to practice externalizing their thought processes and enables modeling with each other. Both result in gains in achievement. However, caution should be used when placing students into cooperative groups. Anderson and Nashon (2006) studied interactions among small groups of students in an amusement park physics program. Individual and small group collective metacognition were studied. A self-

report questionnaire was given to students to assess their metacognitive engagement, as well as recorded conversations while engaged in academic discussion and subsequent interviews with researchers. From this collected data, metacognitive profiles were developed on each student. Learners with strong self-efficacy and weak planning, awareness, and control, tended to be over-confident in their abilities and were less effective in guiding their learning. Not only that, but they were also reported as mandating their over-confident ideas for the group, thus impeding group progress toward valid learning. Learners with weak self-efficacy and strong planning, awareness and control tended to allow others in the group to out-speak them and suppress their ideas. Both instances resulted in less effective functioning of the group, but more importantly, it resulted in students failing to achieve learning outcomes. These findings suggest that the teacher needs to monitor groups closely to ensure that all students are participating, that no student's ideas be rejected out of hand, and that the learning environment supports the ideas of everyone.

While in cooperative groups, discussions can be a simple but effective way to engage students in thinking metacognitively. Hartman (2001a) indicates that through teacher/student and student/student discussions students are required to practice articulating their thoughts in ways that make sense to others. Without these opportunities for discussion, students would only do "sense making" in their heads. By verbalizing their thoughts, metacognition is made transparent, enabling the teacher and classmates to learn from and model each other. It is also important for teachers to model their thinking. Often referred to as "think alouds," this common strategy for sharing one's thinking explicitly conveys the use of metacognitive strategies in action. This is especially important when students are just beginning to experiment with verbalizing their thoughts and can help them persist in this task.

Questioning, when used with discussion, can also be effectively in the science classroom. Hacker and Dunlosky (2003) focus on three metacognitive discussion and questioning strategies comprised of verbal interactions between teacher-student and student-student. *Concurrent* reports involve students communicating out loud about what they are currently thinking. *Retrospective* reports involve students communicating out loud what they have thought about previously. *Prospective* reports involve students communicating "predictions of future performance on a task" (p. 74). Of the three strategies, concurrent reports showed the most promise in studies. When used properly, their use produced significant learning gains for students. According to Hacker and Dunlosky (2003), successful implementation of the concurrent strategy:

1. Promotes explanation of justifications and rationalizations.
2. Uses verbalization to force students to refine their thoughts for listeners.
3. Uses tailored probing questions to identify where a student is in the learning process.
4. Ensures students have enough background knowledge to discuss their thoughts meaningfully. (Yet inappropriately deep questioning can use up cognitive energy that should be used toward the task and lead to disengagement.)
5. Forms questions with the assumption that students will use content strategies to guide their thinking, e.g., "What planning or writing strategy are you starting with?"
6. Treats unproductive responses neutrally. (Explicit prompts usurp students' independence and provide problem-solving directions that they need to develop on their own.)

7. Knows when a student pauses too long or has difficulty sustaining his or her verbalizations. (This is an indicator that students are not ready to verbalize their thinking and are still at the level of acquiring background knowledge for the task.)

If teachers are able to master these discussion and questioning techniques, and teach them to their students, this research clearly indicates metacognitive and achievement gains will follow.

Another form of discussion is feedback. Learning occurs more rapidly when feedback is provided. Feedback that is provided immediately, targeted to address specific areas, and centered on gently communicating patterns of "constructive failure" is most effective (Hartman, 2001b, p. 150). In this way, students are able to use the feedback to diagnose and adjust their own learning when it matters most – in the moment.

DiGisi and Yore (1992) focus on how students approach reading scientific text and what they learn from it. Five universal strategic reading skills are identified to help students with scientific text:

1. Pre-reading or advanced organizers.
2. Recall of prior knowledge and preconceptions or misconceptions.
3. Text mapping to show relationships among the concepts in the text.
4. Identifying patterns in the text.
5. Providing summary questions for understanding at the end of each section.

The effectiveness of these strategies seems to be determined by the age, reading level, and cognitive ability of the student, and does not necessarily improve as the student gets older. Therefore, it is incumbent upon the teacher to consider providing class time so that student reading is closely monitored and actively modeled.

Finally, another effective method of teaching metacognitive strategies in the science classroom is reciprocal teaching. Reciprocal teaching strategy takes advantage of discussion and questioning techniques. Webb (1982, p. 434) states, "The [reciprocal teaching] method is based upon a [two-way] dialogue between teacher and student where predicting, question generating, summarizing, and clarifying are used to promote comprehension monitoring."

According to Bransford et al. (2000), reciprocal teaching consists of three components:

1. Teachers providing instruction on the use of metacognitive strategies and then providing opportunities to practice through opportunities crafted so students mediate their understanding.
2. Teachers initially modeling metacognitive strategies with 'think-alouds'.
3. Teachers using small group settings where students and teachers reciprocate facilitating and modeling metacognitive strategies for each other.

According to Hartman (2001c), the use of scaffolding as a strategy is also effective at teaching metacognitive skills. Scaffolding is based on Vygotsky's "zone of proximal development," which says teaching should be on the level of the student's needs. Therefore, the guidance and support provided by the teacher is only used long enough for the student to begin to become competent, at which point the support is *faded*, turning the responsibility for the learning back over to the student.

Hartman (2001c) further indicates visual images, concept maps, graphic organizers, and vee diagrams for modeling concepts all help facilitate cognitive and metacognitive reflection on learning. Wall & Higgins (2006) used cartoon templates as an unthreatening way to promote metacognition. Students discussed, then recorded their thoughts regarding whatever learning activity they had just completed. Each template showed a scene of a teacher, a student or

students, and portions of either a classroom or another learning environment. Beside each drawn character were thought bubbles. Students wrote their thoughts about learning experience in terms of making their metacognitive strategies overt. One such task involved asking students to reflect on the use of a new interactive whiteboard. The templates were not just associated with traditional learning activities; they were also used to evaluate the impact of technologies and classroom structure on the learning environment.

These visual models make student conceptions transparent, assisting in diagnostic interventions if warranted. They also make possible dynamic group interactions around the creation, interpretation, and revision of the visual models. These models often provide insight regarding the internal mental models students hold.

The Role of the Secondary Science Classroom Environment

For metacognitive strategies to be most effective, students need to be surrounded by a classroom environment that supports metacognitive tenants. One such tenant is high expectations. Too often students perceive the school as a place that values memorization and rote learning rather than deep, conceptual thinking that supports the use of metacognition.

In a study by Case and Gunstone (2002), students using shallow, information-based approaches did not show any significant metacognitive development. But students using sporadic or deep conceptual approaches, the algorithmic learners, did show metacognitive development. The authors cite that it is difficult for students to make the switch to using deep, conceptual approaches and that there are definite classroom approaches the teacher can take either to make this transition more likely or to inhibit it. While students often use the same thinking strategies out of habit, they are not necessarily fixed (Ramsden, 1988). Students can change strategies depending on the educational contexts. Therefore, if an understanding of what

comprises these contexts is identified, the educational environment can be manipulated to potentially induce the use of certain strategies. Marton and Saljo (1976) also support the view that students are capable of using both deep and surface learning strategies. However, they contend that students more often use surface strategies, not because they are not capable of using deep strategies, but because they view the current context of school as valuing surface learning strategies such as memorization and the recall of facts. Therefore, it is recommended that teachers use assessment systems that use open-ended and higher-order questioning, thus requiring deep strategies. If a student perceives that a deeper strategy is needed they will switch to one if they know how and are motivated to do so.

Roberts & Erdos (1993) indicate curricula that embed thinking skills along with the learning provide the structure for learning metacognitive strategies and providing the various experiences to apply them. Case and Gunstone's (2002) study also noted that teaching metacognition is best done in the context of the content classroom rather than as a stand-alone 'study skills' type program. By teaching metacognition in the regular classroom, transfer is not only increased, but the students' perceptions of what type of thinking is needed (deep vs. surface) tends to shift from surface to deep, because that is what is being emphasized by the instructor. Elements identified as being supportive of deep processes are (1) time in class for discussions, (2) more time for group work, and (3) consistency across courses to insist on deep processes rather than only in one course.

The Role of the Secondary Science Teacher

Before teachers can instruct students on the use of metacognition, teachers themselves need to be competent users. Teacher intervention and modeling is needed as students begin to grasp metacognitive processes. Hobson (2008, p. 3) says: "Students who received direct

instruction, modeling of processes and guided practice of comprehension monitoring were able to independently apply these skills later on." Hobson further submit teachers who "demonstrated better metacognitive strategy instruction also produced students who made better progress in metacognitive knowledge" (Hobson, 2008, p. 5). And, this improvement lasted for up to four months after the instruction and modeling stopped. The implications of this study are powerful.

Teachers can provide experiences for students to engage metacognitively. They can model metacognition for students, and help them to develop the self-efficacy required to engage in metacognition when tasks become more difficult. Teachers also need to recognize that learners can come to the same conclusions for very different reasons based on their individual differences and mental models (Hartman, 2001c). Therefore, teachers need to become adept at ferreting out students' reasoning, especially through think-aloud strategies.

Redish (1994) argues that teachers need to change their own mental models about what is effective for students rather than simply being concerned with what is effective for themselves as instructors. Teachers can delude themselves into thinking that if they believe the lesson is good, then it must be educationally sound. Teachers must not forget that they serve *students*.

Finally, the importance of supportive, mentoring relationships cannot be understated. These positive relationships build important trust. When it comes time for students to take risks in the science classroom, this relationship is the foundation, which supports students and can give them the courage to try more difficult learning when they might otherwise disengage.

The Role of the Secondary Science Student

The primary role of the student is to be *involved*. Teachers want students to engage in group discussions with each other and with them. Similarly, teachers want students to feel good about their learning and the inevitable struggles that accompany rigorous academic work. Doing

so increases self-efficacy and increases the likelihood that students will remain motivated. As students gain confidence and autonomy, their ownership of the learning process also increases. Flavell (1987) promotes the idea that as children develop a sense of self and self-efficacy, they are more likely to feel they are capable of taking control of and influencing their own learning. This is the goal of teaching metacognition.

Metacognition Strategies in Educational Assessment

Although inquiry and problem-solving are the current hallmarks of science education, White and Fredericksen (2005) emphasize research which reveals the importance metacognition also plays in the classroom when it is properly infused. In turn, metacognition can also be a powerful tool in assessment, not in the sense of assessing *for* metacognition,” but rather “assessing *with* metacognition.” Pintrich (2002) says metacognitive strategies should not be assessed on standardized or other exams; they are only to be used to facilitate learning. In other words, it is not advised that metacognition itself be assessed, but rather the outcomes that result from it.

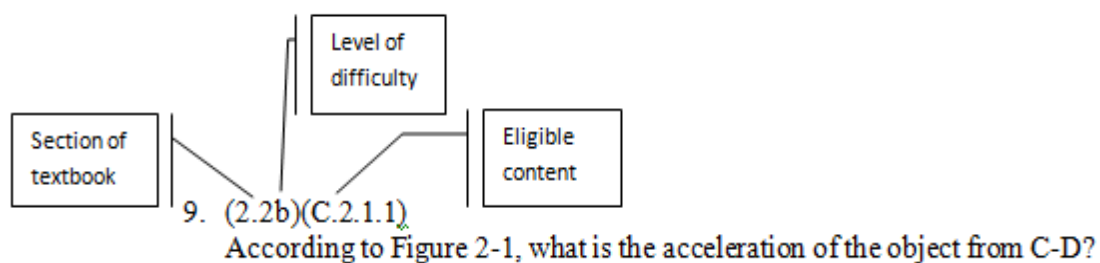
As standardized exam usage becomes more prevalent and it becomes more likely that teachers will be held individually accountable for the success or failure of their students, gains in student achievement become more important. Teachers, if willing, can make students their partners in the assessment process. In other words, teachers can allow students to see how assessment is structured and used by making the assessed curriculum transparent through test-coding, separating different types of questions, using diagnostic sheets following summative assessments, and sharing the resulting data with students.

Science courses typically convey information through two main types of questions: “content” and “nature of science” questions. By separating nature of science questions (such as

graphing, experimental design, and data analysis) from content questions (such as Newton’s Laws of Motion), students can more easily be prompted to engage in metacognitive strategies to solve them. This is especially important for high school freshmen, many of whom have only recently made the cognitive transition from concrete to more abstract thinking. This separation cueing can aid students in activating metacognitive strategies.

Test-coding involves marking each question on a summative exam with the eligible content/objective it measures, the section of the book or lab in which it was learned, and the level of difficulty of the question. (See Table 1.)

Table 1. Sample of coding strategy.



When this coding strategy is shared with students, it becomes a marker for recall of prior learning. When used properly, this provides an opportunity to activate metacognitive strategies that students can employ in solving the question. In this way, students do not have to rely on memory alone. Instead, the coding acts as a specific prompt which guides the student’s approach to the question.

Test-coding also facilitates the use of diagnostic sheets after the summative exam has been graded. (See Table 2.) Students are given a matrix separated into sections by eligible content and/or objectives. Students then follow the test-coding to categorize each question on the exam. They rank their achievement in each area to see whether they have mastered content, have yet to master it, or are undecided about their level of mastery. The students then use these

results to develop a specific tutoring and study plan. This empowers students to take accountability for their learning and helps them practice the “expert learner” mindset of planning. Doing this after each summative exam also helps students track their own progress over time.

Table 2. Sample of test-coding diagnostic sheet.

| Section | # of questions you got right: | # of total questions in the section | % of section you got right | SECTIONS IN WHICH YOU DID WELL | SECTIONS WHICH NEED MORE WORK |
|---|-------------------------------|-------------------------------------|----------------------------|--------------------------------|-------------------------------|
| 1.1 Q. 1-4 Objectives A.1.1, A.1.2, A.1.3 | | | | | |
| 1.2 Q. 5-8 Objectives A.1.4, A.1.5, A.1.6 | | | | | |
| 1 3 | | | | | |

Finally, the achievement teachers expect from students is only as good as the information shared with them. When students take standardized exams or classroom formative and summative assessments, teachers are obligated not only to share their own performance, but also to disclose the overall data. Doing so allows students to assess their performance in relation to the larger picture of the course and their peers. Teachers cannot expect students to buy into a process in which the importance of the results is hidden from them. If teachers wish students to take an active interest in their own education then teachers must be willing to make them privy to the data they possess on their achievement and the implications that data has for their progress.

Challenges to Metacognition in Secondary Science Classrooms

Metacognition can be highly effective in natural science classroom learning environments. However, its effective implementation is not guaranteed. Metacognition thinking is not easily taught; nor is it easily transferred. Therefore, teachers need to understand the sources that can erode metacognitive progress in their classrooms.

Teachers cannot merely promote the use of metacognition and expect students to employ it effectively (Hacker & Dunlosky, 2003; Paris & Winograd, 1990). In fact, student "reflection is not always accurate and may even produce distorted views of one's thoughts" (Nisbett & Wilson, 1977, p. 73). Previous learning can be the basis for new learning or hinder it, twisting it into what it is not. It is critical that teachers make transparent the preconceptions and misconceptions of their students. The story *Fish is Fish* is commonly used to describe the phenomena of *mis-integration* of information into cognitive constructs. In this story, a tadpole departs a pond, leaving his fish friend, in order to become a frog. Later the frog returns to the pond to visit his fish friend and attempts to describe all the wonderful things he has seen during his time in the wide world. As the frog tells his tales, the fish attempts to integrate this new information into his existing construct of fish; fish with wings, fish with horns, fish with legs. The fish is unable (and more importantly, unaware that he is unable), with his current set of experiences, to properly integrate the new information accurately. The parallel is students are often unaware that they do not understand something. And unfortunately, according to Vosniadou and Brewer (1989), these mis-integrations endure and are extremely difficult to eradicate.

In the Case & Gunstone (2002) study, elements identified as damaging to deep processes, and therefore to metacognition, were "heavy workload out of class and the time pressure in assessments" (p. 468), especially for those who were just beginning to experiment with a conceptual, deep approach. If teachers want students to focus energy on employing metacognitive strategies, they also need to be willing to provide them the time and space to do so.

Age and experience (or rather, the lack thereof) can also impede the use of metacognitive strategies. According to Houtveen and Van de Grift (2007) metacognitions could be called

second-order cognitions, requiring more engagement of executive functioning than first-order cognitions. These executive functions and the metacognition that can develop with them mature as a person gets older and gains additional and broader experiences in diagnosing their learning. Hobson Houtveen and Van de Grift contend younger children are not nearly as good at metacognition as their older peers, mostly because they have not had the same number of experiences.

According to Livingston (1997), metacognition suffers when learning is too easy. She argues metacognition does not actually activate until one decides to evaluate whether a strategy will or will not work. Therefore, if a student is not even asking himself these questions and simply passing over unsuccessful learning experiences, he or she is bound to continue to encounter the same pitfalls in those learning experiences. Metacognition is at its best when learning failures occur. Therefore, it would seem that one responsibility of the teacher would be to provide students with conceptually-challenging problems, instruct students on these metacognitive strategies, and then give multiple and varied opportunities to put them in practice.

Bransford et al. (2000) suggest motivation is also an important factor that impacts the time people put into learning. If tasks are too difficult or too easy, motivation declines, from either boredom or frustration. A person's mindset influences his or her level of motivation to engage a task. If a person has a fixed mindset, he or she is likely to disengage from a task. If a person has a growth mindset, he or she is likely to engage in the task. Social interactions and task relevance are also important factors in motivation. When students can be involved in a collaborative effort that is relevant to them, then they are more willing to engage effectively in the task. Ultimately, it is the responsibility of the student to choose to engage in the learning

environment, but teachers have a significant responsibility for providing the conditions to see that they do.

Conclusion

Metacognition is the orchestration of implementing, monitoring, and reflecting on one's thinking. The use of metacognition facilitates a framework under which meaningful discourse can more fully occur in secondary science classrooms. Students *and* teachers need to engage in the components and practices of metacognition. Doing so deepens the meaning of learning opportunities and facilitates a greater likelihood that concept transfer to discrete and novel learning will occur. Making unconscious metacognitive processes conscious allows for their purposeful and strategic application.

Although not all attempts at teaching metacognition have been successful, research shows the inclusion of metacognitive strategies in the science classroom improves student achievement when they are (1) pervasively imbedded in the educational structure, (2) part of an appropriately rigorous and relevant curriculum, (3) supported by 'metacognitive friendly' teaching strategies, (4) explicitly practiced by students *and* teachers, and (5) dedicated to enabling students to take responsibility for their own learning. These value-added practices promote resiliency and persistence in the face of frustration or lack of knowledge.

Teaching our students these enduring thinking strategies is a gift that will empower them to advocate for their own learning needs throughout their education and beyond.

References

- Alter, A., Oppenheimer, D., Epley, N. & Eyre, R. (2007). Overcoming intuition: Metacognitive difficulty activates analytic reasoning. *Journal of Experimental Psychology*, 136(4), 569-576.
- Anderson, F. & Nashon, S. (2006). *Predators of knowledge construction: Interpreting students' metacognition in an amusement park physics program*. Retrieved from <http://www.interscience.wiley.com> (DOI 10.1002/sce.20176).
- August, D. L., Flavell, J. H. & Clift, R. (1984). Comparison of comprehension monitoring of skilled and less skilled readers. *Reading Research Quarterly*, 20(1), 39-54.
- Borkowski, J. G. (1992). Metacognition theory: A framework for teaching literacy, writing, and math skills. *Journal of Learning Disabilities*, 25(4), 253-257.
- Boulware-Gooden, R., Carreker, S., Thornhill, A. & Joshi, M. (2007). Instruction of metacognitive strategies enhances reading comprehension and vocabulary achievement of third-grade students. *The Reading Teacher*, 61(1), 70-77.
- Bransford, J., Sherwood, R., Vye, N. & Rieser, J. (1986). Teaching thinking and problem solving. *American Psychologist*, 41(10), 1078-1089.
- Bransford, J. D., Brown, A. L., Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.
- Case, J. & Gunstone, R. (2002). Metacognitive development as a shift in approach to learning: An in-depth study. *Studies in Higher Education*, 27(4), 459-470.
- Cooper, S. (1999). *Theories of learning in educational psychology: John Flavell:metacognition*. Retrieved from <http://www.lifecircles-inc.com/Learningtheories/constructivism/flavell.html>
- Costa, A. & Kallick, B. (2008) *Learning & leading with habits of mind*. New York: ASCD.

- DiGisi, L. & Yore, L. D. (1992, March). Reading comprehension and metacognition in science: Status, potential and future directions. Presented at the National Association for Research in Science Teaching Annual Meeting. Retrieved from ERIC database (ED 356 132).
- Dweck, C. (2006). *Mindset: The new psychology of success*. New York: Random House.
- Everson, H. T. & Tobias, S. (1998). The ability to estimate knowledge and performance in college: A metacognitive analysis. *Instructional Science*, 26(1-2), 65-79.
- Fisher, R. (1998). Thinking about thinking: Developing metacognition in children. *Early Child Development and Care*, 141(1), 1-15.
- Flavell, J. H. (1979). Speculations about the nature and development of metacognition. In F. Weinert & R. Kluwe, eds., *Metacognition and Motivation*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Flavell, J. H. (1987). Metacognition and cognitive monitoring: A new era in cognitive-developmental inquiry. *American Psychologist*, 34(10), 906-911.
- Georghiades, P. (2004). From the general to the situated: three decades of metacognition. *International Journal of Science Education*, 26(3), 365-383.
- Glaser, R. (1984). Education and thinking: the role of knowledge. *American Psychologist*, 39(2), 93-104.
- Hacker, D. J., Dunlosky, J. (2003). Not all metacognition is created equal. *New Directions for Teaching and Learning*, 95, 73-79.
- Hartman, H. J. (2001a). Developing students' metacognitive knowledge and strategies. In H. J. Hartman (Ed.), *Metacognition in learning and instruction: theory, research, and practice* (pp. 33-68). Dordrecht, The Netherlands: Kluwer Academic Publishers.

- Hartman, H. J. (2001b). Teaching metacognitively. In H.J. Hartman (Ed.), *Metacognition in learning and instruction: Theory, research, and practice* (pp. 149-169). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Hartman, H. J. (2001c). Metacognition in science teaching and learning. In H. J. Hartman (Ed.), *Metacognition in learning and instruction: Theory, research, and practice* (pp. 173-201). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Hobson, E. (2008, July). *The role of metacognition in teaching reading comprehension*. Retrieved from <http://metacognition.org>
- Houtveen, A. A. M. & Van de Grift, J. C. M. (2007). Effects of metacognitive strategy instruction and instruction time on reading comprehension. *School Effectiveness and School Improvement, 18*(2), 173-190.
- Jones, B. F. & Idol, L. (1990). Introduction. In B.F. Jones & L. Idol (Eds.), *Dimensions of Thinking and Cognitive Instruction* (pp. 1-14). Hillsdale, NJ: Erlbaum.
- Karelina, A. & Etkina, E. (2006). When and how do students engage in sense-making in a physics lab? Presented at the Physics Education Research Conference. *American Institute of Physics*. Retrieved from EBSCOHost database (978-0-7354-0383-3).
- Lamport, M. & D. Yoder (2006, Spring). "Faithful gestures: Rebooting the educational mission of the church", *Christian Education Journal, 58-78*.
- Larkin, J.H. & Simon, H.A. (1987). Why a diagram is (sometimes) worth a thousand words. *Cognitive Science (11)*, 65-69.
- Lionni, L. (1970). *Fish Is Fish*. New York: Scholastic Press.
- Livingston, J. A. (1997). *Metacognition: An Overview*. Retrieved from <http://gse.buffalo.edu/fas/shuell/CEP564/Metacog.htm>

- Paris, S.G. & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B.F. Jones & L. idol (Eds.), *Dimensions of thinking and cognitive instruction*(pp. 15-51). Hillsdale, NJ: Erlbaum.
- Piaget, J. (1973). *The language and thought of the child*. London: Routledge & Kegan Paul.
- Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and Assessing. *Theory Into Practice, 41*(4), 219-225.
- Pressley, M., Wharton-McDonald, R., Mistretta-Hampton, J. & Echevarria, M. (1998). Literacy instruction in 10 fourth-and fifth- grade classrooms in upstate NewYork. *Scientific Studies of Reading, 2*(2), 159-194).
- Redish, E. F. (1994). The implications of cognitive studies for teaching physics. *American Journal of Physics, 62*(6), 796-803.
- Roberts, M. J. & Erdos, G. (1993). Strategy selection and metacognition. *Educational Psychology, 13* (3/4), 259-266.
- Salmon, A. (2008). Promoting a culture of thinking in the young child. *Early Childhood Education Journal, 35*, 457-461.
- Slavin, R. S. (1980). Cooperative learning. *Review of Educational Research, 50*(2), 315-342.
- Vosniadou, S. & Brewer, W.F. (1989). The concept of the earth's shape: A study of conceptual change in childhood. Unpublished paper. *Center for the Study of Reading*, University of Illinois, Champaign.
- Vygotsky, L.S. (1978). *Mind in society: The sevelopment of the higher psychological processes*. Cambridge, MA: The Harvard University Press.
- Waltke, B. (2005). *The book of proverbs: Chapters 15-31*. Wm. B. Eerdmans.

- Wall, K. & Higgins, S. (2006). Facilitating metacognitive talk: a research and learning tool. *International Journal of Research & Method in Education*, 29(1), 39-53.
- Webb, N. M. (1982). Student interaction and learning in small groups. *Review of Educational Research*, 52(3), 421-445.
- Weinert, F. (1987). Introduction and overview: Metacognition and motivation as determinants of effective learning and understanding. In F. Weinert & R. Kluwe, eds., *Metacognition and Motivation*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- White, B. & Fredericksen, J. (2005). A theoretical framework and approach for fostering metacognitive development. *Educational Psychologist*, 40(4), 211-223.
- Whimbey, A. (1975). *Intelligence can be taught*. New York: Bantam Books.