

## Role of Metacognition in Facilitating Conceptual Change Learning

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The inclusion of current environmental topics, such as global climate change, ozone depletion and ozone pollution in our introductory environmental science curriculum at the University of Missouri-Kansas City provides an opportunity for our students to learn about ongoing environmental issues, connect classroom materials and 'real life', and develop a pro-environment attitude. However, this task is not without challenges. This is because our students frequently come to school with preconceived notions of the nature of these problems. After teaching the introductory environmental science laboratory to different student populations for ten consecutive semesters I have observed specific misconceptions among my students, regarding global warming and ozone depletion. Even after instruction, many students still held the idea that the ozone hole causes global warming.

Students enter their science classrooms with a wealth of knowledge. They construct their own ideas about how the world works and explain scientific phenomena in terms of these ideas. These kinds of notions are referred to as naive beliefs, misconceptions, alternative conceptions; and such preconceptions seldom match the scientific explanations that are taught in science courses (Wandersee, Mintzes, & Novak, 1994). These misconceptions may have been influenced by their prior experiences, textbooks, teachers' explanations or the media (Toby, 1997). Addressing these inaccurate notions through instruction has been a challenge to science teachers because students' misconceptions are notoriously difficult to change (Kerr & Walz, 2007). Numerous studies, conducted in different parts of the world, show that students come to class and leave, with the same content misinformation even when the content is directly dealt with in class (Khalid, 2003; Cordero, 2002; Nazario et al. 2002, Jeffries et al., 2001).

What could a teacher address during instruction that might facilitate conceptual change in students' ideas? Conceptual change is generally defined as learning that changes an existing way of thinking. Many researchers have demonstrated the importance of mental management (monitoring and control of thoughts) or metacognition, as a means to support the restructuring of ideas in science. Blank (2000) reported that students in the metacognitive classroom experienced a more permanent restructuring of their understanding. Misconceptions are a special category of knowing-not knowing, in which students think they understand a concept, but their understanding is fundamentally incorrect (Eylon & Linn 1988). According to Groves & Pugh (2002), these cognitive illusions may act as hindrances to understanding complex environmental issues such as global warming, stratospheric ozone depletion and tropospheric ozone pollution.

My goal is to help my students overcome mental blockages due to pre-existing knowledge so that they can clearly distinguish between the causes and effects of closely related environmental phenomena. My present plight is how to structure my lessons to include metacognition as an instructional tool that enables students to be confronted with their personal beliefs, realize that these are not accurate, and be led through constructing

a scientifically more correct model (Zirbel, 2006). This requires students to constantly ask self-directed questions and reflect on their own learning. By attending this workshop, I hope to learn more about metacognition, especially its role in facilitating conceptual change.

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## Encouraging Students to Learn How to Learn

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Metacognition encompasses learner-centered processes that monitor progress and adapt strategies for acquiring knowledge through self-awareness of actions necessary to achieve learning objectives. It often occurs spontaneously in expert learners, whereas novices typically require instructional scaffolding that encourages reflection, aids recognition of the scope of understanding, and provides directed guidance to enhance comprehension, overcome bottlenecks, or redress misconceptions.

In teaching introductory classes in the geosciences I endeavor to prompt students to be cognizant of their learning styles and depth of understanding through a variety of in-class and on-line activities. Completion of self-test exercises coupled with learning prompts that identify key concepts for each theme provides individual measures of comprehension, reexamined by comparison of answers in student pairs, then substantiated or corrected by class discussions. Persistent repetition of this activity in every lecture session inculcates students' recognition that their learning benefits from reflection and corroboration. Complementary on-line assignments further reinforce this process, and provide clear evidence (via bonus questions linked to attendance) that students who have been engaged in the reflective class activity possess a deeper understanding of targeted topics. These assignments also provide student feedback identifying which parts of each exercise were challenging or difficult to understand, and those that were beneficial to their learning. The more insightful comments tend to derive from the more accomplished students, which provides supporting evidence of the benefits of metacognitive activities. A similar pattern exists in the responses in assignments that require students to propose and answer both multiple-choice and short-answer questions for a forthcoming exam. Their compositions vary greatly in complexity and difficulty; some are shallow focused on simple memorization of facts, whereas the best are thoughtful constructions deeply rooted in reflective learning of key concepts.

The geosciences represent a fertile discipline for development of metacognitive skills because it requires students to comprehend discrete sets of information and interconnect them to build their understanding of fundamental concepts. For example, a critical challenge in studies of the evolution of the Earth is the integration of knowledge derived from diverse sources, such as the ability to identify a rock specimen from its mineralogy and texture, advanced conceptually by the capacity to place it within a spatial and temporal framework using varied clues from paleontology, stratigraphy, and structure, and then to combine all these elements to reconstruct its history. This challenging and complex task demands that students seek answers from lines of evidence presented by the specimen. It involves an investigative process that is readily adaptable to a metacognitive approach through focusing on the acquisition of reasoning skills involving self-assessment of the basis of each component of knowledge.

In my experience the greatest challenge in efforts to encourage metacognition among students is the inherent divergence in their learning styles that lessens the viability of

generalized recommendations to encourage reflective study. It appears that varied resources – oral and visual explanations, use of analogies, instructional aids, and stepwise guides – differ markedly in terms of their effectiveness in advancing learning outcomes for individual students. A major challenge in efforts to create scaffolding to encourage use of metacognitive processes is identifying approaches that can cater for distinctive student learning styles. An on-line exercise could potentially achieve that goal through design of a matrix of questions structured around pathways that include specific modules tailored to identify and subsequently center on developing particular learning attributes.

## Metacognitive Strategies for Teachers and Undergraduates in the Geosciences

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Metacognition is a process in which we monitor our own learning and recognize ways of successful learning. It involves managing thoughts, and organizing and synthesizing them in ways that lead to the successful completion of a task or problem. It also involves building connections between information and categorizing it based on its relevancy to the problem.

Currently, I am involved with teaching climate science to teachers working on the Crow and Northern Cheyenne Indian Reservations in eastern Montana. We use both face-to-face meetings and web-based discussions and activities. In the course, we use self evaluation/monitoring techniques, such as self-score cards, where the teachers evaluate themselves on their progress. At the end of each face-to-face meeting we ask the teachers for their "muddy points," or topics and concepts they did not understand from the activities that we completed for an individual learning module. This requires them to evaluate between learned and unlearned material. Several topics addressed in the course receive a lot of media attention, such as ozone depletion and global climate change, so I have the teachers brainstorm what they know about the topics before they start the module. They then revisit their lists after going through the material and evaluate their understanding of the subject before and after the module. I have found that using concept maps is another useful tool that helps the teachers connect and organize the information they have learned. Finally, I have them keep a "scoop notebook" where they develop an activity for their students based on one or a series of modules, implement the activity in their classroom, and determine how well the activity was carried out and what the students learned. This process requires the teachers to take the scientific information they have learned and develop it for their grade school students.

I have also taught both upper and lower division courses in physical geography. One activity that I incorporate into all my courses is environmental journals. Students connect concepts or terms discussed in class with examples in their everyday lives. In my weather and climate course, for example, students keep a weather journal and make note of weather forecasts, their own observations, and the accuracy of day to day weather forecasts. The journals are very important for large classes where it is impossible to take students into the field. In my smaller courses, I have students present a topic connected to the day's lecture or as part of a research assignment. The challenge for the student is to present their main points in a clear and concise fashion in a short period of time.

I have noticed an apparent difference in motivation to learn between my teachers and undergraduates. The teachers are motivated by the desire to see their own students succeed beyond the reservation. They see the relevancy of topics in their lives and on the reservation because they are active participants in the community. Teachers also understand what it is like to be a teacher and they understand what you are trying to accomplish. Some undergraduates are taking a class (especially the lower division courses) simply to fulfill a requirement. So it is important to instill motivation by giving

students a purpose to learn and developing ways for them to monitor their own motivation. In my undergraduate courses, I give a brief introduction to the subject and then give them a chance to tell me what they expect to learn from the class and the potential it has to influence their lives. This tells me what is important to them and I can draw on those interests more in my lectures and activities.

I am interested in learning more about teaching metacognition in my courses at a variety of different levels from GK-12 through graduate school. I have not formally studied how to use metacognition in my classroom and look forward to a workshop devoted to the topic. I want to learn about current research on teaching metacognition in the geosciences and about techniques and tools that I can use with my students. I am involved with web-based courses, so I am particularly interested in learning metacognition techniques specific to this teaching environment.

## Metacognition and the Challenges of Teaching Geosciences in an Era of Fundamental Change

by Thomas Brown, Department of Physical Sciences, Austin Community College

I am relatively new to geoscience classroom teaching, having spent much of my career in the technical and consulting world. I am in the process of reconfiguring my presentation strategies from conducting client training and technical seminars to teaching at the undergraduate level. Ideally, I do not see myself as the dispenser of geologic facts and figures but rather as a catalyst for each person to develop their own worldview—their own paradigm on how they see reality.

In the community college environment, very few students are likely to major in the geosciences, so it is my philosophy to present geosciences as "science and the citizen" in a manner that addresses general interest while providing a strong foundation for those who might elect to major in the geosciences or associated fields. As far as the application of metacognitive practices is concerned, I see my role as assisting students in the development of their own worldview, using and developing their own intellectual "tool kits" for personal knowledge and success whatever the outcome of their education.

I find the classroom to be challenging, especially given the various degrees of academic preparation among the students, and their diverse educational backgrounds. Many of my students do not have a strong background in the basics of scientific methodology, chemistry, geography, mathematics or evolutionary theory; or even a well-developed intuitive sense of these subjects. There is a special need for the training of critical thinking. The scientific method is especially well suited for this purpose.

When I extend what I experience in my own classroom to the world at large, implications arise to the challenges we face teaching any technical and scientific subject. There can be no doubt that large-scale structural changes are coming forward in the world involving new systems of global finance, nonhydrocarbon-based energy generation, new technologies, population pressures, geopolitical instabilities and global climate change all intersecting at once. My concern is not just imparting knowledge about the geosciences to my students, but helping them develop their individual worldviews and metacognitive abilities to fathom the nature of these subjects. To be an engaged citizen these days, one must be able to assimilate and parse an enormous amount of information (much of it of suspect quality), while remaining intellectually, emotionally and spiritually balanced in an increasingly challenging politico-economic environment; and yet make educated, even enlightened, decisions on the basis of reason and logic.

Teaching scientific methodology is critical, as we appear to be in a revolution of thought and belief impacting our perceptions of economic, scientific, geopolitical and political affairs. An emerging paradigm derived from the current structure will ideally rest on the shoulders of classical science, involving research, critical thinking and creativity, as these approaches have proven to be of inestimable value. While it seems that scientific

methodology will be preserved going forward, there may no guarantee of such, unless we impart it to the next generation.

My goal as a teacher is to consider new ways to present material, engage my students within the context of geology or environmental science and additionally, help them improve upon their own intellectual processes. I can show them the water and encourage their thirst, but it is ultimately their responsibility and desire to go and drink.



How Do I Study for Your Exams? Or, But, I Studied and Studied and Studied and Still I Didn't get a Good Grade on your Exam!

Metacognition is a word that meant little to me initially; however, with some investigation of the literature I could find, and the announcement for this workshop on metacognition, I have found that this word may open a door to solve one of the most frustrating aspects of my teaching. Metacognition is defined in numerous ways, but the definition that I now find exciting in the sense that I feel it will truly improve my ability to help students learn is as follows: "awareness or analysis of one's own learning or thinking processes" (Merriam-Webster, 2008).

I am unsure if I ever questioned or analyzed how I learn until after a few years of teaching. I was dumbstruck when a student first asked me how to study! To me, studying was like running – I just did it without thought. I never paid any attention to the methods I used to learn, and I am quite sure I never had anyone tell me how to learn. This makes me rather useless when faced with the situation of a student saying to me: "I studied so hard for your exam and I still did poorly, so I am wondering if you can give me some suggestions as to how to study?" All I have been able to do by way of helping is to parrot what I have read in books on how to study; yet, I think I have helped only a few students in this manner. I think it is easy to teach students that many of us would claim as "smart" and who require little work – that is, they just "get it." But I know that I truly feel like I am a good teacher only when I reach and shine the light for a student who didn't "get it." And this is where I must improve.

Since I began teaching I have both struggled and been amazed by the different ways that people think. The different ways of thinking are never as clear to me as when a student asks a question and I have one or two responses in my head: 1) how in the world does the question the student just asked have anything to do with what I was talking about? or 2) never in my life would I have approached this topic or line of thought from that point of view! It can take my breath away and cause me to sit down immediately with the significance of the difference in thought. The various ways in which I have sincerely tried to teach to different learning styles include giving in-class assignments to do as groups – ranging from answering questions in the texts to completing crossword puzzles, using visual imagery to its fullest, offering lecture materials online (via Blackboard or WebCT), calling upon students regularly during lecture, showing films, and using animated illustrations to put forth new concepts. I tell students to not treat their texts as novels, but to outline and read and reread after skimming the chapters; I set up group study sessions with experienced facilitators; I encourage the use of flash cards or online exercises provided by the textbook publishers: yet my methods are really like casting a wide net in the hopes that it will work for some more by accident than plan.

I think and I hope that if I learn more about metacognition, I can help specific students figure out how they learn so that they improve their study habits and so that they are most successful at learning. I hope to learn of geologic exercises that will allow the students to analyze their learning processes and to improve them. A friend of mine who is a history professor made a very astute assessment about many of our students: yes, they read and they reread, but with a few simple exercises, one can see that the reading comprehension is close to abysmal at times. It is the reading comprehension, or ways to learn the material that I am most interested in improving so that my students learn, so that

their work is more efficient, and so that their frustration levels decrease noticeably. And, I think it is important to accomplish these tasks in a transparent manner so that the students clearly understand why I teach in varied ways, and why some of the assignments I hope to come up with after learning more about metacognition are so important and have meaning to them.

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## Metacognition and Cultural Diversity

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I am a faculty member in the Department of Postsecondary Teaching and Learning (PSTL) in the College of Education and Human Development, UMN. The population in PSTL is more diverse than any department within CEHD. Engaging and teaching a diverse population requires a variety of methods that can only be developed when we, as educators, understand our students' thinking processes. To understand how to best teach diverse populations, we focus our research on how students' cultures, experiences, 'lenses' affect students' learning, and how our students are thinking. Our department is approaching these questions from 'multiple perspectives. One such perspective is through the teaching and assessment of our First Year Inquiry (FYI) course. Another perspective is provided from courses taught by the faculty from various disciplines within PSTL.

The First Year Inquiry course: As we are a newly formed multidisciplinary department CEHD and CEHD is now admitting first-year students, we have a unique opportunity to develop a new first year program for all incoming students. The first year program is completely integrated and includes a multidisciplinary first-year inquiry (FYI) course and learning communities. The FYI course is required for all incoming students and is team-taught by 3 Faculty from different disciplines within our department. All FYI lectures design content around one overarching question; students are then exposed to the exploration of that question from multiple perspectives. One of our expected student learning outcomes for this course is that students will be able to identify problems and recognize that all problems can be addressed from different perspectives. In order for students to achieve this outcome, they must first begin to understand who they are, and how their experiences, past and current, affect their thinking. To this end, the first year inquiry course requires reflective writing practices such as weekly journaling. The journaling is critical to both the student and teacher, providing insight to both the learning and teaching process.

PSTL1171 Earth Systems and Environment: In addition to participating in the FYI, I teach an introductory geoscience course. My main goal in teaching this class is to increase students' scientific literacy and critical thinking skills. Some of these goals can be evaluated by assessing changes in attitudes towards science. Over the last year, I have administered the Colorado Learning Attitudes about Science Survey (CLASS; Adams, et al. 2006) instrument, modified for geology, to students enrolled in introductory geology courses (GEO1001 and PsTL1171) at UMN. This survey consists of 42 questions that measure students' pre- and post-course attitudes towards geology and physical sciences. GEO1001 is a large lecture course where the laboratory content is independent from lecture content. PSTL1171 is offered through the Department of Postsecondary Teaching and Learning; this course has smaller class sizes, and lecture and laboratory content are fully integrated. Overall, responses from all students surveyed show a positive shift in attitudes and confidence. However, the pre-course data for individual students from both classes show interesting differences. Students of color in PSTL1171 responded much more favorably in the pre survey for the following categories: Real World Connection,

Physical Science general learning and Physical Science learning confidence. Demographically, students of color comprise 23% of the student population in GEO1001, in contrast to 73% in PsTL1171. Students of color in PSTL1171 are predominantly immigrant and first generation college students. The fact that these students responded more favorably to the above categories before the class indicates a greater sense of awareness for the sciences and their learning capabilities. The question now becomes how do cultures promote positive attitudes and thinking about learning.

In an increasingly diversifying population, addressing such questions is becoming more important in order to become more effective in our teaching practices.

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## Some Slightly Random Thoughts on Metacognition

By Mimi Fuhrman, Rock Solid Testing Services, Carlsbad, CA

I am a geoscientist who has worked for most of the last 20 years in the development of standardized assessments. My formal educational background is in igneous petrology – my expertise in evaluation and assessment development comes not from involvement in educational research, per se, but rather from on-the-job experience. My interest in the role of metacognition in geoscience learning stems from my past work in assessments in geoscience and other disciplines, as well as my more recent interest in the modeling of both the cognitive and affective domains of "geoscience" as a discipline. I started thinking about my own answers to questions such as:

- \* What makes someone (for example, me) self-identify as a geoscientist?,
- \* In what ways do geoscientists habits of mind differ from other scientists?, and
- \* What do I like about being a geoscientist?

As I discussed these questions with fellow geoscientists and others, I realized that many experts have never considered what their own answers would be. In fact, I discovered that there is a tendency for geoscientists to have trouble defining what exactly "geoscience" is, let alone think about their own personal relationship with the discipline.

In my work as a test developer, I have developed a habit of thinking about thinking. A necessary step to the development of a quality test item is to figure out how to write the question so the test-taker is directed to demonstrate the intended thinking process and/or skill. When possible, test developers run test items through cognitive labs in which students are trained to "think aloud" while they attempt to respond to the test items. Using these labs, test developers can revise and refine test items so that the students in the target audience are more likely to respond to the item in the way that is intended. In my current work helping high-school students prepare to take college admissions tests, I find that it helps students to think about what exactly is meant by the test question – what does the question intend to test? For that matter, what should the question intend to test?

Ah! But that is the most important question! I have found that asking high school or college faculty the question "What do you want to find out if your students know or can do?" is first answered with a blank stare...followed in most cases by a twinkle of understanding and then an "Aha!" and "That's it?" when I repeat their answer and say "That is what you should test."

So my interest in metacognition lies at several levels. First, I am very interested in discovering what expert geoscientists come up with when they turn their attention to their own metacognitive processes. I am especially interested in the results of these processes – the answer to the bulleted questions above. Then at the next level, I am interested in how expert views about geoscience as a discipline differ from novice views, and what strategies can we use to eliminate cognitive and affective barriers, especially those

specific to the geosciences, so that our students (novices) can gain a more expert view. Cutting Edge workshops in 2005 and 2007 spawned the development of the Geoscience Concept Crystal (Fuhrman and others, 2005) and an initial model of motivating synergy between affect and cognition in geoscience (Fuhrman and others, 2007) --- my hope is that this workshop will result in the extension of these models to include metacognitive skills.

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## Laboratory Earth: Using Content Mastery Activities (CMAs) as a Mechanism for Integrating Cognitive and Metacognitive Skills to Enhance the Learning of Earth System Science

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As I reflect back over the past 15 years and my work related to the professional development of pre- and in-service K-12 educators related to Earth system science, my colleagues and I have tried to design learning environments that are learner-centered, knowledge-centered, assessment-centered, and community-centered as advocated by Bransford et al. (2000). Over the past few years, we have transitioned much of our professional development activity from face-to-face activities to the on-line environment. We have developed the Laboratory Earth series of online, distance-delivered courses. As we have developed these courses, we have become increasingly committed to taking advantage of the strengths of online delivery. We want to develop distance delivered courses that equal or surpass face-to-face methods. Each course we have designed employs a multiple learning strategies approach (Gardner, 1992) to help participants successfully meet the learning outcomes. The learning strategies include: narrated PowerPoint presentations, field-based activities, video, kitchen labs, simulated experiments, interactive visualizations, individual reading assignments, research projects, online writing responses to open-ended questions, and on-line discussion.

I am admittedly a novice learner regarding metacognition, but developing this essay has provided an opportunity for me to realize that one of the objectives of helping our students develop their metacognitive skills is for them to become more confident, independent learners. Independence leads to ownership as students realize they can pursue their own intellectual needs and discover a wide open world of information at their fingertips. Metacognition requires us to develop a plan as to how to approach a given learning task, monitor our comprehension, and evaluate progress toward completion. Planning, monitoring, and evaluating are higher order thinking skills that require active control over the cognitive processes engaged in learning. However, according to Livingston (1997), cognitive and metacognitive strategies are closely intertwined and dependent upon each other. Any attempt to examine one without acknowledging the other would not provide an adequate picture. In this context, within our online graduate-level Laboratory Earth courses and an undergraduate course entitled Earth's Natural Resource Systems, we provide an opportunity for students to take control and employ these higher-order skills through what we call content mastery activities (CMAs). We do not explicitly teach metacognitive skills, but through CMAs students indirectly use the basic elements of metacognition to achieve the cognitive goal of learning the Earth systems concepts in a particular learning module.

The Laboratory Earth professional development series, developed through funding from NASA, consists of three, three-credit hour, graduate level, distance-delivered, online courses designed for K-12 educators. Our approach to strengthen the scientific qualifications of K-12 classroom practitioners is to use I2A; that is, each course seeks to

integrate science content, inquiry-based learning, and the application of science to "real world" situations and issues. We emphasize that the Earth is a system, which consists of many subsystems, in which everything is connected to everything else (ECEE).

In the Lab Earth courses, we want participants to focus on learning, not grades. Unfortunately, grades have to be issued. Our grading strategy has evolved to a system that uses content mastery activities (CMAs) to document the participant's ability to master course content. The CMAs are available at the beginning of each module. In theory, this should provide the students the opportunity to plan their approach to completing the task, monitor their learning in the context of their plan as the module progresses, and evaluate their level of understanding after the completion of the task using instructor feedback. Activities consist of a scenario that presents a problem or situation and a rubric that outlines the general expectations for their response. Students choose and plan their own approach to synthesize their knowledge and understanding of a module's material and to address the scenario. Formats used include traditional essays, power-point presentations, newsletters, newspaper articles, concept maps, poetry, photo essays, and movies. If the materials presented do not address the elements of the rubric, the student is asked to reevaluate, revisit and resubmit the activity. The student can resubmit as many times as they want. The goal is for the student to be intrinsically motivated to learn the material and reduce the use of grades as a motivator, which distracts from learning. We want everyone to acquire the required concept knowledge and understanding.

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## Metacognition: Self-Awareness of Knowledge Construction Process

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In the current education field, the process of learning is described as learners' active construction of concepts. That is, learning is viewed as the construction of new knowledge by connecting new information to what learners already have. This is in contrast to memorizing facts and terms presented by teachers or textbooks.

According to cognitive scientists, two types of knowledge are involved when we construct knowledge. One is declarative knowledge that refers to "knowing that". The other is procedural knowledge that refers to "knowing how". Let's think of playing with a picture puzzle. We have lots of small pieces of puzzle at the beginning of a game, but it is not meaningful until we construct the full picture. To understand the full picture, we need to connect each piece, and only after we assemble all of the pieces would the picture reveal a meaning to us. In this metaphor, how to connect each piece of the puzzle means procedural knowledge while the full picture means declarative knowledge. That is, procedural knowledge provides a structure for meaningful declarative knowledge. Similarly, to understand a particular knowledge, we need to connect each concept that we already have. Consequently, without procedural knowledge, we do not obtain conceptual understanding; rather, the most we can expect is rote memorization.

In this view, Hofer (2004) proposed that the nature of epistemology, which is the nature of the theory of knowledge, is an aspect of meta-cognitive awareness that is activated in knowledge construction processes.

Then, as educators, how do we help students develop their metacognition and how do we assess students' metacognition?

Two conditions are necessary to help students develop their metacognition. The first condition is students' actual experience in constructing knowledge through inquiry teaching methods or constructivist pedagogy. Most of literature stated that inquiry teaching is an effective method for students to develop both declarative and procedural knowledge that are activated during that construction process. For example, Smith, Maclin, Houghton, and Hennessey (2000) found that a constructivist pedagogy helped students develop understanding of their own knowledge construction. More specifically, they found that science curriculum in which students work in groups to investigate phenomena, develop their own ideas or theories for explaining the phenomena, engage in experimentation, and discuss with each other was helpful for sixth grade students to develop more sophisticated understanding of epistemology of science.

The second condition is the chance to reflect the process of knowledge construction that students were actually involved in. It is necessary that students actually have experiences in constructing knowledge, but simply involving them in learning to construct knowledge is not enough for students to be aware of the knowledge that was constructed during the

learning experience. According to Dienes and Perner (2002), simply thinking of something does not make one conscious of the thought. To be conscious of the thought, they must represent what they have thought. In other words, unless students have a chance to reflect the thought or knowledge that have been developed through experience of knowledge construction, their thought or knowledge might stay in an unconscious level. Therefore, for awareness of the process of knowledge construction, students need to have an opportunity to reflect their thought process of constructing knowledge through various representation tools (e.g., scientific method chart, argumentation tool).

In our introductory biology labs for non-majors, we use the following argumentation tool:

If ... HYPOTHESIS is assumed to be correct

And... we TEST such and such

Then... such and such should be observed (EXPECTED RESULT)

And/But... such and such was observed (ACTUAL RESULT)

Therefore... hypothesis is supported or not supported (CONCLUSION).

This tool uses a format that was fit for argumentation using a scientific method (Lawson, 2003).

Also this representation tool will be able to use as a good assessment tool. That is, through the argumentation tool, not only teachers can see students' thought process step by step but they also check up students' logics and reasoning to construct knowledge.

Why is it important to teach metacognition?

A central goal of science education is to help students become scientifically literate (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). NRC (1996) defines scientific literacy like this:

Scientific literacy is being able to read with understanding articles about science in the popular press and being able to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it (p. 22).

Align with the main goal of science education, teaching metacognition in science curriculum is able to help not only understanding of important scientific concepts but also improving critical thinking skills.

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## A Case Study of a Student's Reflective Thoughts: A Vision for Practice

M. Gertrude Hennessey

"Learning is considering my own ideas and how they fit together. I like to consider my own thinking because I can understand more about why I think the way I do. I can also learn about the science communities' ideas the same way. For example, I can compare my classmates' ideas to mine and by doing this it helps me to build a bigger and stronger or more complex description of what we are talking about. My classmates and I also can do the same thing when we are considering a scientist's ideas. It's really the same you know-thinking about someone else's ideas and trying to see it from their perspective.

To learn, I think you need a good understand of your ideas about the topic before you can do anything else. For example, when I stopped to think about my ideas of how gravity works, they make perfect sense to me. I remember the big debate we got into in third grade over how gravity worked: Did it push? Did it pull? Now the debate is much more complex and centers on comparing and contrasting our ideas to Isaac Newton's ideas; and trying to figure out what he meant by parts of his theory; like the influence between two objects, no matter how far apart never decreases to zero. Now, that I find intelligible but certainly not plausible!

I think learning in science is about wondering about the world, how it works, and then asking yourself questions that you find challenging. I think a good analogy for learning is a puzzle. You can have all 1000 pieces but if you don't take the time to fit them together you will never see the picture. Most school learning is like collecting the pieces of the puzzle and keeping them in a box. Teachers reward you for collecting enough pieces, the more pieces you collect the better rewards you get!

I think learning in our science class is much different. Back to my analogy of the puzzle. In science class we spend a lot of time trying to fit the pieces of the puzzle together. Sometimes it takes all of us working together to fit one piece of the puzzle into its right place in the picture. The analogy isn't perfect because there is only one way to fit the pieces into the puzzle. But in science there is more than just one way to fit science ideas together.

To me, learning is the work you do as you fit ideas together. Using you experiences, talking with others in class, building and testing models that represent your ideas all help you to think about how ideas fit together; and that, I think makes for good learning."  
(Kathryn, Project META 1994)

How would you best describe this student's thoughts about her learning experiences in science? How would you describe her approach to learning science? Based on the comments provided by the student in the vignette, what "vision of practice" would you construct about the pedagogy practices operating within the student's science class? Before proceeding, take a moment to record your reflections to these probes.

## Making Cognition and Metacognition Explicit

High among the many purposes of education is the conjecture that higher levels of cognitive activity are important to learning and intellectual development. There seems to be two components to this goal, one to do with cognition (viz., problem-solving, heuristic, planning) and the other to do with metacognition (viz., knowing that one knows). The two parts are closely related, because during intellectual development one sees the acquisition of not only traditional subject matter and related skills but also a more general knowledge that seems to be useful across a broader, subject-independent domain. To varying degrees, one can consider the result of these higher level cognitive activities as intellectual functioning and knowledge development. Thus, cognition is about organizing one's own intellectual resources efficiently and metacognition is about what one knows about his or her own thinking or thinking processes (Flavell, 1976). One of the most exciting educational implications is the leverage that one may expect by enhancing intentional learning (Hennessey, 2003) at the cognitive and metacognitive levels.

During the past three decades, researchers in philosophy of science, cognitive psychology, and science education have begun to elucidate some fundamental understanding of the dynamic role of the learner in developing conceptual knowledge and engaging in higher-level cognitive activity. Until recently, these communities worked almost entirely exclusive of each other. With the current resurgence of epistemological interests in both the science education and cognitive psychology communities (Perry, 1970/1999; Carey et al., 1989; Cary and Smith, 1993; Smith et al., 2000; Hammer and Elby, 2002; Randolph, 2005; Sandoval, 2005) questions concerned, albeit in different ways, with the nature of science, students' personal epistemologies, and science teaching have emerged. This epistemological turn is evidenced in the significant increase in academic activity and research which, in turn, has had important implications for approaches to science teaching and learning at all levels of education.

Despite the relatively rich research history in both cognition and metacognition, no consensus has emerged as to the nature of higher-level knowledge. My intent within this brief essay is twofold. First, to describe a class of higher-level knowledge associated with the process of metacognition. The class is higher-level in that it is knowledge about science knowledge rather than science content per se. Second, to argue for a transparent link between metacognition and intentional learning as the underpinnings that supports conceptual understanding in science.

### Metacognition

The precise definition of metacognition is a subject of some debate. Despite the terms widespread use, researchers' views of metacognition are varied and influenced by the disciplinary area they study (Hacker et al., 1998). The stance adopted here is that metacognition is an internal construct: "an inner awareness or process, not an overt behaviour" (White, 1988). This inner awareness can be about what one knows (content

knowledge), one's learning process (knowledge construction), or one's current cognitive state (awareness of mental constructs). I reserve the term for conscious and deliberate thoughts that have ideas as their object (Hennessey, 2003). Abilities such as execution of strategies, employment of heuristics, regulation of behaviors, coupled with motivational aspects of learning have the potential to lead to success on a given task. These competencies, as desirable as they may be, do not guarantee an awareness of one's own inner thoughts or an ability to contemplate the rational arguments used to support one's knowledge claims. Rather they are the observable features of successful performance (Hennessey, 2003). This does not mean that learning strategies or self-regulating tasks cannot occur within the metacognitive realm. To do so, is a more complex task involving knowledge or awareness by the learner that these are appropriate strategies to apply in order to execute the tasks successfully. This awareness entails, not just selection of the correct strategies to employ, but a reflection on other potential or competing strategies to know why they are effective or ineffective; or if selected, what errors or positive effects may result (Hennessey 1999). The distinction is analogous to that proposed by Kuhn et al, (1989): the ability to think about the significance of a specific strategy as opposed to merely unreflected execution of a set of strategies.

#### Discussion: A Focus on Metacognitive Processes

Returning to the vignette, when synthesized into a conceptual whole, and combined with the conviction that metacognition is inherent in the process of conceptual understanding and intentional learning the following picture emerges from Kathryn's essay. First, the metacognitive process rests on sensing states of mind and having a language to describe states of mind (Hennessey, 2003). Kathryn's language contains rich common sense vocabulary for the phenomena of thought. At times, in order for her to describe her state of mind she utilizes metaphors drawn from the physical world. For example, the student spoke about building descriptions, or fitting science ideas together into a conceptual whole. At other times she gave anthropomorphic attributes to descriptions of her ideas (e.g., bigger and stronger). Even these terms hardly do justice to the mental events Kathryn wishes to describe.

Second, the vignette provides ample evidence that Kathryn has no difficulty engaging in metacognitive processes. The metacognitive process she reveals, by externally representing her thoughts on what she believe to be good science learning, takes place at both the representational and evaluative level. Understanding this grading or priority structure, I believe, may be the key to understanding the relationship between metacognition and intentional learning and an underpinning that supports conceptual understanding of science content (Hennessey, 2003; Yuruk, et al., in press).

Metacognition processes at the representational level (an inner awareness of Kathryn's unobservable constructs about science learning made public through written discourse) may include an intentional component or it may not. The ability to merely represent one's internal constructs may take place at either the algorithmic level or the intentional level. The issue here is one of automaticity. Kathryn's processes at the evaluative level, her ability to: (a) consider the basis of her beliefs in a specific conceptions (nature of

scientific learning); (b) temporarily bracket, or set aside, her conceptions in order to assess competing conceptions; (c) consider the relationship among her conceptions and any evidence that may or may not support those conceptions; (e) consider explicitly the status (intelligible and plausible) of her own and other conceptions; and (f) evaluate the consistency and generalizability inherent in her conceptions are more likely to take place at the intentional level. The sophisticated nature of these processes makes it less likely that they are not automatic. Both aspects of metacognition are important learning for conceptual understanding, however. The first relates to the moment-to-moment control of cognition that promotes students; ability to monitor and fine tune their thinking as they work towards goal directed tasks. The second relates to critiquing cognition.

This essay opened with the voice of a student in order to give the reader a small window into a constructivist-based class. If the reader listens carefully to Kathryn's voice the reader will notice that the metacognitive capability of this 11-year old elementary school student is far more sophisticated than many researchers have assumed. The issues touched upon in this brief essay, focus on the fundamental question: Can instruction of metacognitive processes facilitate intentional learning and conceptual understanding of science content? Does it have an effect? I believe it does have an effect. The educational environment created for Kathryn (and her peers) successfully allowed a cohort of 11–12 year old students to engage in various types of metacognitive processes: both at the representational and evaluative levels throughout the course of their science classes.

In closing, I would like to pose the following question: As practitioners in our respective fields of endeavor, what "vision of practice" can we develop for ourselves that will support our students' ability to develop more sophisticated metacognitive processes? The opening vignette clearly demonstrates that, in addition to developing sophisticated metacognitive abilities, this student's school science had dramatically affect the development of her epistemological stance about the nature of science learning – an important issues to be considered, which is beyond the scope of this essay!

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## Brain Development and Long-Term Memory

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The aspect of learning that most interests me is long-term declarative memory formation. Three aspects of brain development influence memory formation for college-age students: 1) the phenomenal growth of neurons and connections made among them that occur from adolescence to early adulthood and the subsequent pruning of neuronal connections ("use it or lose it"), 2) the impact of this growth on how declarative memory can be created and stored for the long term (hippocampus activation), and 3) the somewhat competing phenomenon of the lag in development until early adulthood of the part of the brain that governs impulse inhibition, prioritization, and strategizing (dorsolateral prefrontal cortex).

Memories are more readily formed and retained when created during this life phase than in later years. Stressors enhance neuronal connections: fear stimuli enhance neuronal connections in the amygdala, the seat of fear, aggression and emotional responses. Repetition and mnemonic devices act as stressors on the hippocampus, the seat of long-term memory. We have the opportunity to help students learn to create and retain memories and to develop some late-developing parts of the brain that govern spatial awareness and understanding. Maps are an excellent tool to help the brain develop spatial awareness.

Getting students to focus on these tasks and to see their importance can be challenging because of the late development of the parts of the brain that reduce risk-taking, control impulses and weigh consequences. For activation of the hippocampus (movement of short-term to long-term memory storage), students need to devote time to a task (and repeat the task), have sufficient sleep, eliminate distractions (yes, ipods, twittering, im, texting, etc.), and avoid alcohol. Some research indicates that an additional stimulus while studying, such as white noise or a consistent scent, can help memory consolidation.

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## Mississippi Learning: Personal Experience with Metacognition with Different Student Populations

By Julia Johnston, Department of Geosciences, Mississippi State University, Starkville, MS

Education courses were not included in the curriculum of my Geosciences degrees. I was aware of the concept of metacognition, but was not familiar with the lexicon associated with it. Therefore, my experience with the concept of metacognition is exclusive to personal observation.

During the research for my thesis, I read some basic papers about learning styles, cognitive levels, self-assessment, and teaching methods to reach a broad range of students. During the 5 years of teaching basic Earth Science courses for mostly non-majors, I have observed some of these concepts in practice, and tried to adjust my teaching styles to accommodate different classroom populations.

My first teaching at the college level occurred as part of my thesis research, when I became the Lab Coordinator for the Earth Science I (Introductory Geology) courses at Mississippi State University in Starkville. These labs enroll 300 students each semester, taught by 6-8 Graduate Teaching Assistants, who worked under my supervision. My research centered on gathering data from a baseline semester, and then making incremental changes to the lab in subsequent semesters and assessing the impact of the changes on the students' learning. The student population in these labs is almost entirely traditional students, non-majors, many of them studying education, business, or arts, or undecided. Students majoring in other sciences or engineering are almost absent from our enrollment. There is also about an even division of African-American and Caucasian students, representative of Mississippi State's general student population. Very few Hispanic or Asian students (maybe 6 or 7 out of the 300) were in our course.

After receiving my Master's degree, I was immediately hired as an adjunct instructor at multiple colleges. I was hired by the Geosciences Depart at MSU, where I had earned the degree, to teach lecture sections of Earth Science I, Introductory World Geography, and retain my position as Lab Coordinator. The student population in each course was similar to that of the labs. I was able to apply several of the teaching methods that resulted from my thesis research to the lecture courses as well. I found that these traditional students rarely approached me with questions about how to study or learn until after midterm grades, and then only after earning a D or F for a midterm grade.

At the same time, I was approached by Mississippi State's extension campus at Meridian to teach the same Earth Science I course, at first in a once-a-week night class, and eventually in an online format. The student population in this course consists mainly of nontraditional, working mothers, many of them single parents, approximately 75% African-American, who are taking evening classes to earn a degree and enhance their employment opportunities. I quickly found that it was necessary to adjust my teaching methods to accommodate different learning styles and the mostly independent-study

nature of these courses. Just this semester, Fall of 2008, I have also been developing an accompanying online lab course which is taken by a subset of the lecture students. These students often approach me for ideas about learning and studying techniques in the first few weeks of the semester, indicating that they are attempting to assess their learning styles and adjust their methods accordingly.

Also during the same semesters, I began teaching Introductory Geology and World Geography at the Mississippi University for Women in Columbus, 25 miles distant from Starkville. Although the name is no longer entirely appropriate, as they allowed male students to enroll beginning in the late 20th century, 85% of the students are still female, and about an even distribution of traditional and non-traditional students, as well as African-American and Caucasian students. The majority of the students are majoring in either nursing or education, and there are no geology majors, as my course is the only geology course offered. These students begin in the first or second week of class working together in groups, and trying various study methods to help each other learn the material. There is a non-competitive interaction between them that excludes me from their metacognitive development, but helps them to be independent and interdependent.

In my experience, distributions of age, gender, major field of study, and lifestyle have a profound effect on the students' metacognitive development. If we can adjust our teaching styles to accommodate these differences, we should be able to expect increased learning in not only our Geosciences courses, but in all areas the students will study in their academic careers.

## Metacognition and Team Based Learning

by Francis Jones, Carl Wieman Science Education Initiative (CWSEI) and Department of Earth & Ocean Sciences, University of British Columbia

Metacognition is a very broad term encompassing many related aspects of learning. Descriptions of metacognition in two commonly cited books illustrate the breadth of the issue. Bransford et al (2000) describe metacognitive abilities as those that focus on sense-making, self-assessment, and reflection. These abilities are noted as an important part of distinguishing experts from novices. The authors suggest that characteristics of pedagogies addressing metacognition include: (i) explicit support for developing relevant frameworks; (ii) encouragement of abstraction; (iii) conscious evaluation of progress; (iv) learning specific content in some depth; and (v) persistent awareness of the learners' foundational knowledge. Handelsman et al (2006) refers to metacognition as "the internal dialogue about what is being learned", and state that it includes "the process of setting challenging goals, identifying strategies to meet them, and monitoring progress toward them". The latter two aspects, in addition to addressing student's beliefs about learning, are also the focus of Lovett's approaches to teaching metacognition (Lovett, 2008).

Given the scope of metacognition, one common thread seems to be that actions (pedagogies) supporting development of metacognition must be rich in feedback. I believe that focused social settings such as discussions, team or group work, tutorials & recitations, or individual tutoring, are the types of situations which are most conducive to provision of ongoing feedback which is highly responsive to both the context and the individuals.

This benefit of focused social settings is one reason I considered using Team Based Learning (TBL) (Michaelson, et al, 2004) to shift an applied geophysics course (roughly 50 students) from a physics / math perspective towards a more applications orientation. I had tried both formal Problem Based Learning (PBL) (Torp and Sage, 2002) and traditional lectures with adhoc group activities, but the first was too radical a departure for this one course within our curriculum, and the second was not producing noticeable improvements in outcomes or classroom behavior.

Many of the details that make up the Team Based Learning strategy are aimed directly at enabling sophisticated learning situations in which students can utilize and develop their maturing metacognitive skills. Generally, the TBL strategy develops and supports highly effective learning teams, and gives them suitably complicated and relevant exercises without the overhead of producing detailed outcomes. Four key components of TBL support metacognitive development as follows:

- \* Permanent teams: If growth of metacognitive skills is supported by high level discussions within a team setting, then the effectiveness of how the learning team operates is a crucial component of fostering that growth. Strong teams depend on trust, adequate preparation, and focus on task, therefore careful construction of teams, time for them to develop as units, and organizational structures to keep teams together and

productive, are all important. Much useful background on what makes teams effective can be found in Birmingham, 2004.

- \* Pre-class readings with corresponding in-class quizzes: Quizzes on required readings and other lower level learning are first done individually, then immediately re-done (the identical quiz) as a team using an instant feedback mechanism. This format supports accountability and team building. It also provides a setting for higher level discussions which presumably support metacognitive skill development.

- \* In-class applications exercises: The majority of class time is spent on exercises that require teams to make complex, multi-faceted decisions, report in very simple forms, then justify and discuss choices as a whole class. Complexity results in rich opportunities for team members to debate, think, and rethink in a focused social setting. Simple reporting keeps the effort on the task of higher level learning rather than generating a communications product. The final class-level discussions provide further opportunities to consider concepts socially and internally, with guidance (i.e. modelling of appropriate metacognition) provided by the expert instructor.

- \* Periodic peer assessment: Ideally, students are given two or three opportunities in the course to evaluate the contributions from team members, the effectiveness of the team as a whole, and their own perceptions about whether individual and team learning goals are being met. This improves accountability and supports reflection about the learning process. Anecdotally, based on traffic on the TBL list-serve, this appears to be one of the most challenging aspects of TBL.

Since beginning to use TBL, I have been pleased by the energy in the class and the sophistication of exercises that students can tackle. Rigorous action research proving enhanced metacognitive abilities has not been carried out, but midterm and end of term surveys do provide data on students' opinions about their experiences (see for example <http://www.eos.ubc.ca/research/cwsei/feedback/350-eot-summary.pdf>). Currently, the course is being taught by a new instructor with very little teaching experience, and his use of the TBL components has been both effective (based on midterm survey results and interviews), and informative concerning the transferability of these techniques.

In conclusion, our anecdotal experiences do suggest that Team Based Learning in this setting is causing students to practice at least some characteristic metacognitive behaviors. We have benefited from plenty of references on team and group behavior (Birmingham, 2004); however, there is no doubt room for focused research on the relationship between learning in teams and development of metacognition.

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## Experiential Learning and the Power of Reflection

Dr. Helen King, Higher Education Consultant

Experiential learning is a term that has different meanings depending on the individual and the context. Learning by doing is a useful definition as it suggests hands-on learning and active participation; compared with the passive, listening approach that might be taken in traditional lectures. However, for me, it also may have some connotations such as simply doing what you're told or following the recipe. Learning by doing brings to mind my own formalised work experience when I was studying at high school, I spent a week at an accountancy firm – the main thing I learnt was that I knew I didn't want to become an accountant! This was a strong contrast to the learning I gained from my various weekend and vacation jobs where I developed a variety of skills such as time management, team working, inter-personal communication, self-motivation and so on. So what was the difference between this formal work experience arranged through my school and my learning through work at the weekends? Well, in the former example I was 'doing' but in the latter I was 'being'.

I believe that the notion of learning by being a geologist, is much more powerful than simply doing geology. For the teacher, it can stimulate more interesting curriculum development ideas and, for the student, a more authentic experience that can help to induct them into the discipline. This might be considered synonymous with learning by inquiry which refers to diverse ways in which scientists study the natural world, propose ideas, and explain and justify assertions based upon evidence derived from scientific work. And so learning by being or learning by inquiry suggests more authentic ways in which learners can investigate the natural world. The learning is hands-on and active; but provides more opportunity for exploration and self-directed learning. Students may work as scientists in either a simulated or real research or consultancy project.

Experiential learning can occur in any well-designed learning environment including lectures; however, geoscience provides many opportunities for active learning outside the classroom and closer to the realm of the professional scientist, particularly through fieldwork and lab work. But is experience by itself enough to ensure learning will happen? What is it that turns experiences into learning? What specifically enables learners to get maximum benefit from the situations they find themselves in? How can they apply their experiences in new contexts? Why can some learners appear to benefit more than others? There are a variety of generic models of experiential learning, the most familiar being that of David Kolb (1984), and as Andresen et al note in their 2000 review of experience-based learning "One consistent feature [of these models] is the central place of reflection [my emphasis]." Similarly, the Geography, Earth & Environmental Sciences Subject Centre Guides to Laboratory & Practical Work (Williams, 2006) and Employability (Gedye & Chalkley, 2006) are both clear on this role of reflection within labwork and work-based learning.

So where might reflection happen within an experience? Boud et al (1985), in their book 'Reflection: Turning Experience into Learning' provide an outline case study of a geology

student on a week-long field trip. The experience has three stages: preparation, engagement in the activity and processing what has been experienced:

- \* Preparation may involve briefings from the lecturer, practice in field techniques and so on. During this time the student will start to explore what is required from them, what the demands of the field setting might be and what resources they have themselves to bring. This phase can often be one of high anxiety (e.g. Boyle et al, 2003).

- \* The field experience itself may initially be overwhelming with new environments, complex features, busy days and little time to reconcile what they are doing in the field with what they have learnt in the classroom.

- \* In the final phase there may be a formal requirement to consolidate their learning, perhaps through report writing, and it is here that students may have more opportunity to look back on and make sense of their experience.

So during the experiential process "Learners are having to cope with a considerable amount of new information, they are facing personal demands and the situation forces them into active involvement whether they like it or not. Reflection is needed at various points: at the start in anticipation of the experience, during the experience as a way of dealing with the vast array of inputs and coping with the feelings that are generated, and following the experience during the phase of writing and consolidation."

So what is reflection and how can we support it? Jenny Moon suggests in her book (Moon, 1999) that common usage of the word implies "a form of mental processing with a purpose and/or anticipated outcome that is applied to relatively complicated or unstructured ideas for which there is not an obvious solution." Perhaps we could translate this into 'taking the time to think about stuff'. Giving this a formal name makes it sound like something else we have to try and fit in the curriculum and, if seen in this way can be prohibitive. However, reflection is not something new or different but something we do all the time as researcher learners. When we go into the field we don't blindly take measurements and analyse them. We observe, we link our observations to our prior experience, we note (mentally or otherwise) any anomalies, we're thinking 'What's going on here?'. But for students the case is somewhat different; if they've never been in the field before they don't know what they should be looking for or how they should go about their work. They will follow instructions. Reflection is the process we go through to make meaning – so it's part of learning how to do science or how to be a scientist. It's not a one-off but part of the whole curriculum. Also it's hard to reflect on something that you've done for the first time as you have nothing to benchmark it against. Reflection should be developed progressively in the same way that other research skills are developed throughout the curriculum to support the student on their journey from novice to expert.

In what ways might we help students to think more about their experiences? One way might be to make the most of / make explicit what do already. For example, in the field note book prompt students to note not just what they see but to write down any links between that and what they've learnt in the classroom; any questions they might have and



so on. Assessment, including self / peer assessment, feedback and group discussions, all provide opportunities for students to process their experience and enhance their learning.

An additional opportunity for reflection might be through participation in geoscience education research. In order to find out what students thinking about when they are on a field trip or working in the laboratory or classroom, it is necessary to get them to be explicit about their experiences and thinking, i.e. getting them to reflect.

If learning to reflect is a progressive process then, at the beginning it perhaps needed to be more strongly guided. Jenny Moon offers lots of interesting ideas of how this might be done but I'd like to share with you an example from the environmental sciences. Paul Wright at Southampton Solent University runs a problem-based learning module in marine pollution management. The aims of the module are to develop student research skills using learning, teaching and assessment approaches which simulate research processes. One of the assessments is by Learning Journal that requires the students to give a week-by-week diary of the content they have read, and to reflect upon this material, identify gaps, and set new learning objectives. Prompts used for the journal include:

- \* What were the main ideas presented in this week's session, and what are my objectives for the coming week?
- \* Have I any difficulties in learning this material? If so, where, and why? Do I need guidance from the lecturer or my group?
- \* What is my opinion of what I learned? Do I believe the issues raised? What are the plus and minus sides of the arguments? Can I criticise the work?
- \* How is the group functioning? Am I being heard?

So experiential learning involves a lot more than simply 'an experience'. Andresen et al (2000) suggest that for a truly experiential environment the following attributes should be present in some combination:

- \* The goal of experience-based learning involves something personally significant or meaningful to the students.
- \* Students should be personally engaged.
- \* Reflective thought and opportunities for students to write or discuss their experiences should be ongoing throughout the process.
- \* The whole person is involved, meaning not just their intellect but also their senses, their feelings and their personalities.
- \* Students should be recognized for prior learning they bring into the process.
- \* Teachers need to establish a sense of trust, respect, openness, and concern for the well-being of the students [experiential learning environments can be out of students' comfort zones, in addition reflection activities may require them to express personal feelings].

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## The Effect of Metaconceptual Teaching Activities on Students' Understanding of Liquids and Solids and Self-Efficacy Toward Chemistry

by Zubeyde Demet Kirbulut, College of Education and Human Services, University of Wisconsin Oshkosh

During the last three decades metacognition has become one of the major fields of cognitive development. Metacognition research began with John Flavell's metamemory study (Flavell, 1971). Over the years, different definitions (for example, Brown, 1987; Flavell, 1979; Riekey & Stacy, 2000) and taxonomies of metacognition (for example, Flavell, 1979; Schraw & Moshman, 1995; Pintrich, Wolters & Baxter, 2000) have been emerged in the literature. Flavell (1979) defined metacognition as "knowledge and cognition about cognitive phenomena" (p. 906). According to Brown (1987), metacognition referred to "one's knowledge and control of own cognitive system" (p. 66). Riekey and Stacy (2000) interpreted metacognition as "thinking about one's own thinking" (p. 915). Many taxonomies of metacognition were proposed by researchers. For example, according to Flavell (1979), the components of metacognition consisted of "metacognitive knowledge" and "metacognitive experience". Pintrich, Wolters and Baxter (2000) proposed another taxonomy for metacognition consisted of metacognitive knowledge, metacognitive judgments and monitoring, and self-regulation and control of cognition. In the literature, it was pointed out that metacognition is a complex and multidimensional construct (for example, Brown, 1987; Flavell, 1987; Georgiades, 2004). Brown (1987) reported two problems related to metacognition. The first problem was the obscurity about what is "meta" and what is "cognitive". The second one is the historical roots of metacognition. Flavell (1987) mentioned about a set of questions concerning metacognition such as "What kinds of psychological concepts are related to metacognition? What aspects of metacognition are inherent and what aspects must be acquired in the course of childhood, adolescence, or even during the adult years? How might various types of metacognition develop?" The evaluation of metacognition is another problematic issue. Many methods for the assessment of metacognition are being used, such as questionnaires, interviews, the analysis of thinking-aloud protocol, and observations. All these assessment methods have their pros and cons. In order to understand this disparity between various assessment methods, multi-method designs are needed (Veenman & Spaans, 2005). Although many obscurities exist related to metacognition as mentioned above, the importance of it in learning is not questioned. Flavell (1979) indicated the important role of metacognition in oral communication skills, reading comprehension, writing, attention, memory, problem solving, social cognition, and various types of self-control and self-instruction. Following this study, Flavell (1987) suggested that "good schools should be hotbeds of metacognitive development" (p. 27). Metacognition is widely believed to make students responsible for their learning, hence more actively involved in the learning process, and there is growing literature advocating positive impact of metacognitive activity on student thinking skills and conceptual understanding (Adey, Shayer & Yates; 1989; Beeth, 1998; Hennessey, 1999; Hewson, Beeth, & Thorley, 1998; Vosniadou, 2008).

The purpose of my study will be to examine the effectiveness of metaconceptual teaching activities on 10th grade students' conceptual understanding of liquids and solids, self-efficacy toward chemistry and durability of their conceptions compared to traditional instruction. Furthermore, the nature of the students' metaconceptual processes will be examined. Therefore, in this study, a multi-method research design including quasi-experimental design and case study design will be used. To examine the effect of metaconceptual teaching activities on dependent variables, two weeks before the treatment, the two instruments Liquids and Solids Concept Test (LSCT) and Self-efficacy Scale toward Chemistry will be administered to students in experimental and control groups. Also, they will be given at the end of the treatment. In addition, LSCT will be given eight weeks after the treatment to examine the durability of students' conceptions. In the experimental and control groups, the tasks such as demonstrations, laboratory experiments, and quantitative problem-solving will be used. On the other hand, there will be some differences in the use of these tasks. In the experimental group, in order to facilitate students' engagement in metaconceptual knowledge and processes several types of instructional activities such as poster drawing, journal writing, small group discussion and whole group discussion will be employed. In the control groups, the teacher will teach with the traditional method. Students in the experimental groups will be taught by metacognitive teaching activities. In order to test the null hypotheses, statistical technique named multivariate analysis of covariance (MANCOVA) will be used. In case study design, the data will be collected from multiple sources such as video recordings of classroom discussions, audio recordings of group discussions, posters, concept maps of the students, and interviews before and after the instructional activities.

This research has potential to inform teachers and teacher educators about the teaching strategies used to promote students' engagement in metaconceptual processes to facilitate conceptual understanding and contribute to a better understanding of the individual students' metaconceptual processes. In addition, this research may lead to understanding of the effect of the metaconceptual teaching activities on students' self-efficacy toward chemistry as a school subject.

Finally, some aspects of metacognition that need to be considered at the workshop could be the discussion on the term itself, how accurately we can assess metacognition, how we can use metacognitive teaching activities effectively in the classroom and how metacognition can be integrated curriculum effectively.

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## Teaching Metacognition: Preparing Students to Be Successful

by Kaatje Kraft, Physical Science Department, Mesa Community College

As a faculty member at a community college I encounter a wide diversity of students' life experiences, academic expectations, and personal goals of the students enrolled in my geoscience courses. I have had students in a single class who range in age from 17 to 65, and in academic preparation may be extremely competent and motivated to very underprepared and lacking an understanding as to how to be an effective learner. Over the last 10 years, I see more and more students arrive underprepared to be successful in post-secondary academics, a trend that is supported by recent studies (Kozeracki & Brooks, 2006; U.S. Department of Education, 2003). Knowing that fewer than 1% of these students will go on to become geology majors, it is important for me to help my students be successful, no matter their major or academic goals. Educational research supports that in order for students to learn most effectively, students must be able to compare their understanding to what they already know, fit the concepts they learn to a big picture and reflect on their learning (NRC (National Resource Council), 2005; Weinstein, Meyer, Husman, Van Mater, & McKeachie, 2006). Recent research indicates that many students lack the skills needed to be successful in the workforce, including critical thinking and self-monitoring skills (Partnership for the 21st Century Skills, 2006).

During the past 5 years, I have worked to integrate these components with the geoscience content I teach. Most recently, I have worked to integrate situated metacognition into my course content. Situated metacognition (integrated metacognition in the context of the content area) is a way to combine key learning skills within a specific course. This integration provided students with the opportunity for changes in their thinking that can lead to conceptual changes over time (Blank, 2000; Georgiades, 2004; White & Gunstone, 1989). Specifically, I have looked to see if I can increase student understanding of the nature of science, especially as it pertains to the process of geosciences, with the integration of situated metacognitive prompts throughout the course content. In order to do this effectively, I teach my class as a scientific classroom discourse community (Yerrick & Roth, 2005). This means that I teach my class from an inquiry approach and students are actively engaged in talking and writing in small and large group settings. Students are also asked periodically to reflect on their learning process both to help them gauge what they know, what they don't know, and what they can do to better understand the content they don't know. This also allows me to receive valuable formative feedback as I teach content and can better address my students' learning needs as I modify my instruction.

To help my students organize their ideas, writing, and course content, I have integrated student notebooks into my classroom. This allows students to learn to regulate their learning through an organizational system, in which support strategies are integrated into the process. Using notebooks as a learning tool provides opportunities for self-assessment, self-organization, and general self-monitoring; all of which are important for developing metacognitive skills (Klentschy & Molina-De La Torre, 2004; Moon, 2006). In the end, I hope to produce students who are more capable at being successful in any

classroom and more confident that they can be successful. I'm not sure my class alone will do that (Weinstein, Husman, & Dierking, 2000), however, it's an important start.

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## Encouraging Metacognition in the K-12 Environment

Nicole LaDue, National Science Foundation

The K-12 public education system heavily emphasizes student knowledge but not always student learning and thinking. For the past 6 years, I taught at a high achieving school district in suburban New York. Most teachers in my school readily employ a healthy combination of the techniques described by Hunter (1994). Aside from the typical constraints of a public school system, I have found that the biggest challenge associated with engaging students in metacognition is frustration. This frustration may be considered the intersection of students' confusion as they hit material that is not attached to a conceptual framework and their self-confidence in their own ability. John Dewey (1910) identified this "somewhat painful" experience as "reflective thinking".

The structure of some pedagogy techniques used on the K-12 level encourage student metacognition (ex. anticipatory set, jigsaw, KWL technique (Ogle, 1986)). One technique I used in my classroom is an anticipatory set. The goal is to have students pre-assess what they already understand about a topic and facilitate the process by which the new material attaches to a students' existing conceptual framework. During the learning activities, using jigsaws helps students monitor their learning by expecting them to teach someone else what they have learned. This often reveals weaknesses in their learning, which enables them to find another resource to attempt to understand the subject matter. This technique has been particularly helpful in my plate tectonics unit. During this unit, students are assigned a piece of evidence (ex. plotting earthquake depth and distance from the Peru-Chili trench, determining plate motion using the ages of Hawaiian Islands, etc.) and then meet in groups to teach each other about their findings. The KWL technique, where students make a graphic organizer of what they already know (K), what they want to know (W), and what they learned (L), is a way of teaching metacognition by providing a structured framework for that process. These techniques promote metacognition but are simple and not particularly time consuming.

With science pedagogy in particular, the geosciences have a unique opportunity. Science generally lends itself to the inquiry method and the geosciences specifically focus on a real-world context making it more accessible to a novice. Thus our discipline should be an ideal setting for the implementation of metacognitive strategies. Despite this, I have found the biggest hurdle with K-12 students is the fine line between challenging and frustrating. Duckworth (1996) encourages us to give students time for their confusion and even the exploration of wrong ideas. In order for students to construct meaning, they need time to build the framework. During graduate school, my advisor always met my expressions of frustration with the phrase, "Confusion is good!" Fortunately, I came to understand and embrace this phrase (and torture my students with it!) as an excellent way to help students realize that their confusion is a vital step in the learning process. It is a sign that metacognition is happening because it implies that they have discovered a discrepancy in their thinking. The hardest part of employing inquiry-based learning is the students' readiness to engage in this style of learning. While maturity may play a role, a

larger factor is practice. If students are used to the "confusion" as a normal part of the process, they are more willing to be uncomfortable.

As a teacher of primarily ninth graders, I have found that while some students are motivated to learn, others are not so interested. The hard part is encouraging metacognition when a student is not inherently driven by interest in content or style of learning. How can their interest be piqued? The key may be a discrepant event. If they become aware of something that does not agree with their conceptual framework, they begin to ask questions almost in defiance of the learning process (or the teacher!) This is the opportunity teachers must grab to ask the right questions to challenge the student's framework and facilitate metacognition (ex. Why does this happen? What other situations does this remind you of? What should we do next to test your idea?)

There are many simple pedagogical techniques that can be sprinkled in to the curriculum stew to encourage metacognition. Of utmost importance is the patience required by the instructor to allow students to be confused and frustrated by the effort required for higher order learning. Often the structure and expectations of a public K-12 environment impede the successful implementation of these techniques (Smith, 1991). However, the capacity for flexibility in undergraduate environment is an exciting opportunity to implement metacognitive techniques. Conditioning students to have patience with the process is essential. It is encouraging to see greater adoption of these techniques amongst undergraduate faculty.

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## Metacognition and Cognitive Load in Teaching Sedimentary Geology

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Two of the major learning goals for undergraduate students in my Sedimentary Geology course are the following:

- \* Given sedimentary data in outcrop, measured sections, or other formats, you will be able to interpret depositional processes and environments.

- \* You will be able to form reasonable hypotheses about the roles of tectonism, sea level and climate, acting through sediment supply, base level, or subsidence, in generating sedimentary successions.

In detail, both goals involve some degree of mastery of complex, interwoven concepts that can be overwhelming to novice practitioners who have neither (1) relevant schema in long-term memory to help manage cognitive load (e.g., Sweller, van Merriënboer and Paas, 1998, *Educational Psychology Review* 10, 251-296), nor (2) extensive practice in metacognitive reflection and learning strategies. In recent iterations of this course, I have experimented with teaching approaches to help students overcome these obstacles. These approaches are presented below as works in progress that are still being refined and that could benefit from feedback from workshop participants.

### Learning-Cycle Approach to Lab and Field-Trip Activities

A learning-cycle approach asks students for predictions before a lab or field trip, has them make observations during the lab/trip, and then asks for reflection on the correspondence between predictions and observations afterward—a structured metacognitive exercise. For example, prior to a field trip to a local barrier coast (<http://serc.carleton.edu/NAGTWorkshops/sedimentary/activities/14170.html>), students predict what bedforms they will find in various sub-environments and explain their reasoning, giving a snapshot of their understanding at that time. During the trip, students visit these same sub-environments at low tide and describe the actual bedforms and interpret the formative flows. They then compare their observations with their predictions and self-evaluate their conceptions and misconceptions, for example:

"Overall most of our predictions were either incomplete or entirely different than what we observed. It had not occurred to me that the flood would be stronger than the ebb nor had I thought to predict superimposed ripples as a result of changing water levels and speeds. It was very insightful to observe and think about water moving through the whole delta and inlet and how it changes with each tide."

An additional advantage to this approach is that students have a clear observational framework when they visit the field, which reduces extraneous cognitive load and allows them to focus on the learning goal at hand.

A similar approach can be used for indoor labs. For example, students are asked to make predictions on outcomes of settling experiments in water and shampoo, giving their reasons for and degree of confidence in their predictions, e.g.,:

"Grains will settle faster in water than shampoo. The shampoo is more dense therefore slowing the rate of displacement...[but] I'm uncertain as to the factors that will slow the particles in the shampoo. What are the controlling forces?"

In this case, the student is aware that she does not have a clear understanding of the forces involved, and can later compare her incorrect attribution of density as being the controlling factor to the concepts of viscosity and fluid drag.

### In-Class Case Studies

In order to give students more practice in interpreting sedimentary successions, and to expose their thinking to themselves and to me, I have them tackle case studies in class. For example, after learning about fluvial systems, students were presented with two Jurassic examples drawn from the literature in which the style of fluvial channel changes up-section and/or the ratio of accommodation space to sediment supply changes over time. Initially, I tried an adaptation of the "reciprocal teaching" strategy pioneered by Palincsar and Brown (1984, *Cognition and Instruction* 1, 117-175), in which students take turns orally interpreting, summarizing, and asking clarifying questions about successive stratigraphic intervals, inviting comments from classmates. Although helpful, this approach did not sufficiently emphasize metacognitive strategies. In a later iteration, I had each student first write out their interpretation of the section, and then had a whole-class discussion that began with the question: "What did you find difficult about interpreting this section?" This invitation to reflect on their thinking and points of confusion—along with the overt expectation that they would find the problem difficult—prompted a focused discussion on what they did and did not understand and led to many clarifications.

### Generic Conclusions/Recommendations

Although the examples here are specific to Sedimentary Geology, there are several conclusions and recommendations that can inform geoscience instruction in general:

1. Be explicit with students about the cognitive difficulties involved in mastering complex problems and the need to develop appropriate cognitive and metacognitive strategies that will allow them to progress from novices toward mastery;
2. Where practical, consider a learning-cycle approach that asks students to expose their thinking to themselves and to the instructor, and has them monitor explicitly the evolution of their understanding;
3. Practice in class, with peer interaction, the problem-solving skills that you expect them to master on exams. Repeated practice on problems that have some elements in common but also include variations on a theme allow students to build and strengthen schema and reinforce difficult concepts;

4. Be aware that the strategies above can be very time-consuming, so that the instructor may have to adjust course content accordingly.

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My primary research interest is the affective impact of assessing and evaluating students. Within this context my efforts have been focused on developing observation tools to quantify student engagement. I've collected three semesters of control group data using this instrument in conjunction with a self-report survey, an achievement test and semi-structured student interviews. The course being studied is a foundation level geoscience course. We are currently in the process of creating assessment for learning (AfL) styled strategies to begin treatment group studies in the upcoming semester.

We describe AfL as non-evaluative feedback to help students define their existing conceptions then develop and implement a plan for achieving specific learning objectives (Black, Harrison, Lee, Marshall, & Wiliam, 2003). AfL has been shown to produce dramatic improvements in student achievement. Carefully constructed formative assessments encourage students to behave as intentional learners. Sources of feedback can be the instructor, peers, or self-assessment. Our intention is to develop a full suite of formative assessments for a given teaching unit in meteorology.

Instructor based formative assessments will be implemented in two forms. First, we'll focus on questioning strategies during whole classroom discussions. Daily outcome questions will also be a venue for formal written feedback.

Peer feedback will be provided both formally and informally. Classroom activities are completed in collaborative groups. Peers provide real-time feedback as activities progress. Peer review will also be the first line of feedback on daily outcome questions and journal entries. Students will be required to provide and receive peer feedback prior to the instructor making comments.

Self-reflection (metacognition) will play a critical role in the implementation and effectiveness of our suite of assessments. We're looking for specific strategies to both teach and assess students' metacognitive skills.

In the past, I've used open-ended questions in the form of reflective journaling with minimal success. Students saw little value in this exercise and were convinced that there was some predetermined right answer I was looking for. When they discovered that these entries were not graded the level of effort dropped substantially. My primary goal in attending this cutting edge workshop is to come away with knowledge and skills to apply to my research project as well as my science methods for elementary educators course.

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## 'How to Think' not 'What to Think'

M. Mamo, University of Nebraska-Lincoln

I teach an introductory level Soil Resources course every Fall semester. Because it is a high enrollment (>110) course with a very diverse majors (15 to 16 majors) and an almost equal percent distribution of freshman, sophomore, junior, and senior, I invest a significant amount of my time on scholarship of teaching and learning. My pedagogy is to develop students 'skill on 'how to think', especially for a lower level course where many underpinning concepts are taught. I believe that students should master the skills in metacognition by the time they are in their third year in college and lower level courses become even more critical in providing opportunities to increase skills in metacognition.

I have taught the course using an active, small-group learning style covering twenty-five soil science topics with 1/3 hands-on activities combined with worksheets, 1/3 with just worksheets alone, and 1/3 on projects. The set-up or design of the course, one lecture a week and 2-two hr meeting a week in small group, actually fits to enhance self-regulated learning although the vast majority of the students cannot embrace too well a semester long course that is almost entirely small group and self-guided without the instructor 'lecturing'. Part of self-regulated learning is planning before the task of activities (small group). This has been and is still a major barrier to self-awareness in learning as most in the class spend less than 2 hours/week spend preparing and reading (Mamo and Kettler, Formal and Informal Surveys, 2003). In 2004, I implemented an online quizzing system done outside of class to encourage reading and course review outside of class. This portion of the course activity is 20% of the course grade. The quiz consists of both lower and higher order level questions and is open for a week at a time. Because the goal of the open book online quiz is to give students incentive to review and read course materials, the quiz can be taken as many times as needed within the week to achieve an 80% mastery level. The online system allows me to track the number of attempt for each quiz, minutes spend at each attempt on a quiz, and the total hour spend on a quiz for each student. Periodically, I ask my small group what they do when they do not succeed on the quiz. The answer almost always is that 'they had to go back and review the readings and supplemental references once or few more times. This has greatly improved amount of hours spend (3 to 4 hours/week) on planning/preparation for the majority of students.

Other activities that I have incorporated to enhance self-regulated learning is situated learning and/or case study which is especially critical in a course with diverse background preparation and motivation level. The central trait of this approach is starting with a compelling problem that provides a motivational context for learners (Koschmann et al, 1996). Context based problems will naturally pose intriguing question or problem; broadening the significance of the question or problem; and engaging students in higher order activities (Bain, 2004). To this end, I have developed and used digital case studies with different context to increase motivation and broaden the application of the subject matter.

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***“Reflections and self awareness of learning styles” Metacognition essay***  
***Jim McDougall***

Our colleges serve very diverse groups of learners and teachers who work toward goals that include self realization, awareness, and confidence. A teacher can foster an environment rich in methods, applications, and experience that will appeal to people with a broad range of learning styles. Students may also benefit from regular patterns and expectations in the classroom that they will recognize and use to chart their progress. Reflection, metacognition, and self awareness of learning processes and activities are valuable in a good learning environment.

Cultivating reflection and metacognition may depend on how we view the content of our subject and what we think is essential to know for a course of study. Our introductory physics courses use explicit inquiry-based experimental methods with predictions, testing, conclusions, etc. Formal and informal teams report their results verbally and in journals, which include reflections about contributions to solving a problem, difficulties faced, modifications, and what to work toward next. Evaluation of poster presentations includes looking at decisions by group members about how problems were tackled. Metacognitive reflections seem relatively transparent here and can be tied directly with the labs. A possible drawback in these metacognitive prompts is their tendency to be rather “one size fits all”.

In geography and the environmental sciences, I use panels, discussions, and guided presentation formats where learning objectives are applied more globally, with summary and feedback along the way. Reflection includes looking at information gathering strategies, fact checking, use of statistics, and what data is applied in forming a model or a viewpoint. Metacognitive activities seem more ingrained, subtle, and less explicit to me than in physics. However, self regulation and adaption of strategies may be more personalized to the needs of an individual student.

My geology courses generally include experiments (like physics) and also make use of exploration and imagination. Metacognitive awareness may include how a learner develops their version of the scientific method to weigh uncertainty and controlled speculation. There are many contexts for methods or strategies of learning and applying experimental models, such as in understanding water percolation, drainage, or flooding. Finding good metacognitive exercises here seems very hard, especially with diverse learners. I listen a lot to students who are willing to tell me how they view a successful learning environment.

Regular reflection by students reveals their awareness about how they might transfer a strategy or method to a new or novel application. For example, my students compared using properties to identify a mineral or rock with using symptoms to define a disease, or using personality traits to form a character in a play. They may look at scientific thinking as being more logical or empirical and apply this in their lives in some fascinating way. Students may develop a scientific habit of mind by weaving interdependent cognitive or

metacognitive “strands” (e.g., Herbert, 2003). The strands may be provided in a course or courses and the “weaving” may be done by the student.

Community colleges are largely commuter campuses and many students benefit greatly from meeting other students they would not easily meet or interact with otherwise. I try especially hard to provide this opportunity in the classroom. Interesting cooperative study groups emerge involving students who vary greatly in age and life experiences. Students can benefit from collective reflective analysis, especially examining adjustments they make to matching their cognition to demands of a class, developing strategies, and trying them out. Students negotiate the status of their ideas in relation to other students or to universally held assumptions on how things work (e.g., Mittlefehldt and Grotzer, 2003).

Expert learners analyze problems to understand them, apply content along the way, generate multiple ideas, evaluate, and assess them as they go, and monitor their progress along the way. I see an overall benefit in empowering the learner and freeing them more from dependence on the teacher. Knowledge of strategies and where to use them and just what we really should be doing is what I hope to gain from our workshop.

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## Effective Learning in Earth Science

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I am a current adjunct earth science instructor, former high school teacher, and future professor of science education when I finish my EdD in a few years. My experience with metacognition started with teacher in-service training. I learned about graphic organizers, two column notes, and Venn diagrams, among other things. There are many excellent techniques for grades 4 to 10. The juniors and seniors in my high school class, however, thought that those techniques were "childish" and they preferred lectures. Realistically, the juniors I taught in the afternoon were no better at note taking and studying than the freshman I taught in the morning. What I did with my older students, which may or may not fall into the metacognitive category, was to give them choices. They could work in groups or work alone, they could choose their own research topics, and they could choose current event articles to bring in and present. By turning over the day-to-day workings of the curriculum to the students, they perceived a sense of self-pacing and autonomy. Overall, I thought it was a more effective strategy than just direct instruction.

Jump ahead four years and I am teaching on Saturday morning at my community college. I have students that are a few years older than before and a lot of adults who are returning to school. Only meeting one day a week precludes using student choice as a daily strategy. Instead, I have started to draw from a field that I just recently learned about: andragogy, the field of educating adults. According to Knowles, Holton & Swanson (2005), there are six attributes that adults have that make them different from adolescent learners.

1. Need to know. Adult learners want to see a benefit to learning.
2. Self-concept. Adults have a self-concept of being responsible for themselves. School can cause a conflict between being dependent on the teacher and program and the need to be self-directing.
3. Experiences. Adults have a wide range of life experiences that they can draw upon to help them learn new information.
4. Readiness to learn. Adults are ready to learn skills that will help them solve problems in their lives.
5. Orientation to Learning. Adults are task- or problem-centered in their orientation to learning. They learn most effectively when the new knowledge, skills and attitudes are presented in the context of realistic situations.
6. Motivation. Adults are motivated to learn by both internal and external motivators. External motivators include increased employment opportunities and promotions. Internal motivators include increased quality of life and increased self-esteem.

The principle of need to know is the most difficult to put into practice. Students in my class rarely take earth science because it will benefit them at work, though I occasionally do have an elementary school teacher who can put my class to use. Experience and problem-centered orientation are the principles I use the most. I use local examples of earth science (limestone pits, the fossil record of Illinois, the Midwest climate) to

illustrate the principles in the text. Frequently, I get thoughtful questions about places my students have been or learn about in a television program they saw. On the other side, some students do not like it when off-subject questions are asked in class; these are typically the younger students. However, I feel that the climate of the class is much better and the class is more interesting when I take all questions from students.

I am eager to learn other perspectives on teaching undergraduates.

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## Thinking As a Geologist: Master-Novice Relations and Metacognition

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For geoscience majors, and to a lesser extent for all students in my classes, one of my main learning objectives is to help students to “think as a geologist”. I certainly want to help students to:

- develop cognitive skills (concept and content mastery) and to work towards higher order thinking skills as defined by Bloom (1956; comprehension, application, analysis, synthesis, and evaluation);
- develop a variety of skill sets (e.g. in the psychomotor domain; Simpson, 1972; Harrow, 1972) that include technical skills that pertain to the geosciences (mapping, sampling, use of instruments, etc.), and life-long learning skills such as communication (writing, speaking, graphical representations), quantitative skills, and interpersonal skills (collaborative and cooperative group work); and
- engage the affective domain (Krathwohl et al., 1973), and directly address their motivations and barriers to learning, personal feelings about learning and about Science, and issues of ethics and values related to the scientific enterprise.

Overall, I hope to help my students develop “scientific habits of the mind” (AAAS, 1989; a compiled list of these attributes is attached at the end of this essay). But to be an effective professional geoscientist (and I would also argue, to be a responsible citizen living on Earth), learners must be given the tools to go beyond simple mastery of knowledge and skill sets. To be able to make truly new contributions to understanding the complex Earth (rather than just recycling old ideas and concepts), learners must also be **self-aware about how they learn** in Nature and from each other in our scientific society (i.e. what are they doing, why are they doing that, with what expected outcomes?), they must be able to **monitor their learning** (i.e. assess whether or not they are effectively meeting their objectives), and know how to **adjust their learning strategies** (i.e. to be able to recognize dead ends, internal inconsistencies, impossible relationships, and to be able to respond appropriately). That is, they need to **learn metacognitive skills** to fully realize their potential as contributing scientists. Here are some of the abilities I hope my students will (begin to) develop in my own instructional activities, and in preparation for future development in graduate school or in employment. Like learning to play a fiddle or hit a baseball, these skills should be practiced early and:

- The ability to extend observations and interpretations from the limited cases we can present in our classes and laboratory exercises and apply these to related situations found in Nature with all its variations and complexity; in petrology courses we try our hardest to provide collections of good, representative samples—but Nature is not always so kind (and not all plagioclase shows good lamellar twins...what other approaches can be used to identify minerals and thus classify rocks?).
- Similarly, the ability to transfer and apply skills (methods, approaches, techniques) appropriately in new situations, and to sufficiently understand the underlying principles and assumptions so that adjustments can be made to accommodate

additional factors that may confound established protocols (i.e. to be able to work beyond “cook-book” and prescriptive approaches; and, the ability to pick the “right tool for the right job”).

- To think critically about what approaches should be used and why. In igneous geochemistry, we can rapidly produce any number of geochemical variation diagrams—but why? All too often, students produce reams and reams of graphs because the computer makes it easy and they saw such a presentation in a lecture, departmental seminar, or journal article. But they should be able to understand why we care about high field strength element (HFSE) depletion, or “enriched” light Rare Earth elements (LREE; and enriched compared to what, and why?)?
- To become critical producers and consumers of data; to understand the full context of how samples were selected and prepared; what analytical instruments were used (were these the best or most appropriate?); what data reduction routines were used and how are the data represented? If any of these factors are unknown or suspect, my hope is that the students will immediately, and rightfully, question the results and interpretations and ask critical (yet respectful) questions; in short, to utilize Cartesian “hyperbolic skepticism” (see end note).
- Making decisions in the field or in the lab about what is important to observe (record, measure, sketch, photograph, etc.), and what can be ignored; this means working within the full context of what we know: about the nature of science, about Nature, about accepted methods and strategies (i.e. our community of practice); and in the selection of appropriate tools and their utilization.
- The ability to recognize when something is “not quite right”. Perhaps there are inconsistencies in the evidence, or perhaps outright contradictions. This should raise a red flag and cause the student to stop and assess the situation. In thin section, a green, high relief mineral, with high birefringence might be interpreted as olivine, but in the presence of quartz the student should know that olivine and quartz don’t occur in Nature together, and a reassessment would indicate that the green mineral is actually epidote. The ability to have an understanding of what is to be expected in a geologic setting, and what is required, permitted (but equivocal in terms of interpretation), possible or impossible in Nature is essential. I hope my students will leave my class being able to make arguments that are at least internally consistent (being “right” is not really an option in most cases when dealing with the incomplete geologic record), and that they will be able to recognize inconsistencies in their own work and in reviewing the work of others.
- Questions asked of Nature, and strategies and methods used to address these questions should be purposeful, not rote (or done by mimicry). Flexibility is a virtue as questions evolve and strategies/methods change as the unexpected is encountered and in light of new evidence. Students should be able to clearly articulate the problem that is being addressed, the significance of the question and how it fits into the context of what is known, what the expected outcomes are, and methods that will be used to test the hypothesis and how to formulate interpretations that are constrained by the evidence.
- When obstacles are encountered, students should know when to stop, reflect, back-up, re-do, test, confirm, go back to first principles, and start over if necessary. Blind

adherence to a charted course without critical reflection can lead to useless collection of information (not data), incorrect interpretations, and professional embarrassment.

My personal interest related to metacognition in the geosciences is to study master-novice relations in an attempt to “unpack” the metacognitive strategies and skills employed by “master” geoscientists as they seek to understand Earth in the field, lab, experiment, and models. Much of what we do as professional geoscientists is done instantaneously, and without conscious thought on our part. I hope to explore the many ways master geoscientists look at Earth in its raw form in Nature, and in its distilled form through our various representations of Earth (maps, graphs, etc.). I hope to begin to clearly articulate the “what” geoscientists are thinking and “why” they choose a particular approach or strategy among the many options available to us. By identifying these strategies and approaches

- These can be explicitly built into class, lab and field activities to provide students the opportunity to develop these skills; at this time, we know very little about how to teach metacognition in geoscience classes, and what skills can best be developed by different types of learning activities and environments; and
- By articulating these skills, this will also help contribute to geoscience research as geoscientists become more self-aware of how we do our Science this will hopefully feed back positively on the development of researchers and the quality of research products.

As a final introductory thought, I have long thought that it is important to take an historical look at how our science has advanced in our standard coursework and have tried to introduce the “greats” of our science to our students by reviewing who they were, what their goals and motivations were, and some of the truly remarkable contributions that they made as examples of how we could conduct our own scientific investigations. I didn’t know it at the time, but I have actually been teaching metacognition in my Mineralogy class by presenting one of the earliest contributions to metacognition: René Descartes’ Discourse on the Method (1637):

*The first was never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgement than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt.*

*The second, to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.*

*The third, to conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence.*

*And the last, in every case to make enumerations so complete, and reviews so general, that I might be assured that nothing was omitted.*

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## Preparing Citizens: Examining the Role of Metacognition in Promoting Life-long Learning

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As members of a modern industrialized and democratic society, Americans are continually faced with a large number and variety of societal issues that have significant technological and scientific components. Although many of these issues address topics relate to Earth science, e.g. resource extraction, use and disposal, water issues, hazards, countless others involve other sciences, e.g. genetically engineered crops, biofuels, or encompass a number of sciences, i.e. climate change, nuclear power. Yet, numerous studies suggest the general public's understanding of science remains woefully inadequate (NCEE, 1983; NRC, 1996; Siebert & McIntosh, 2001; Steen, 2001) thereby leaving them ill-prepared to address the science-social issues they routinely encounter. In hopes of increasing scientific understanding in the general public, many universities and colleges require all students to take a minimum number of introductory science courses. To increase student engagement, many of these courses are developed around pressing social issues, e.g. climate change, energy, etc. While such courses may prepare students for today's problems, they are unlikely to prime them for next year's or those of the next decade. For example, ten years ago how many general science courses would have anticipated the importance of global climate change, global sustainability or biofuel science? Rather than trying to teach students the scientific concepts and principles of the next major social issue with scientific overtones, our introductory science courses should educate them in the scientific process ("habits of mind"), assist them in improving the skills (literacies) necessary to master scientific content (Myers & Massey, 2008) and prepare them to be life-long learners. Armed with these mental facilities, a citizen will be able to educate him or herself about any issue he/she will face in the future.

To prepare my students to be tomorrow's informed and effective citizens, I have radically altered the nature of the courses I teach and the undergraduate student audiences these courses are aimed at. For the past six or seven years, I have developed and taught courses that place Earth science in social context and target both the geology major as well as the non-major. These courses stress the links between society and science as well as the literacies students need to master scientific content. Students are provided explicit help with the fundamental (quantitative and qualitative skills) and technical (mapping reading, spatial visualization and temporal conceptualization) literacies necessary to master the scientific content that underpins many of society's pressing issues (Myers and Massey, 2008). At the same time, the courses stress a set of skills (citizenship literacies) rarely addressed in STEM courses (Massey and Myers, 2006). These skills permit the transfer of scientific understanding to science-society issues in an effective manner while stressing the importance of viewing the issue from a variety of perspectives (economic, social, cultural, political, etc.). These courses have been effective in showing students, both majors and non-majors, the relation between science and society. Despite the success of these courses, it is not clear that they are helping students become life-long learners. Since preparing students as life-long learners is critical in producing a more

scientifically informed and engaged citizenry, the courses are probably not as effective as we would like.

Two recent NRC reports (NRC, 2000; 2005) have pointed out the importance of metacognitive skills in producing efficient life-long learners. Unfortunately, the classes we have developed to prepare citizens for active engagement do not explicitly address metacognition. At the beginning of the semester, I do tell students that I reserve the right to ask them three questions at any time during lab. The questions are: What are you doing? Why are you doing it? and Is it helping you accomplish your goal(s)? These are three questions I would like my students to ask themselves throughout a project. By asking them these questions periodically, I hope to demonstrate the mental process they should be using to self-monitoring their own learning. Unfortunately, I do not know how effective this technique is. During the workshop, I hope to learn more about the theoretical basis of metacognition, be introduced to its literature, learn a variety of techniques for teaching it and discover means to assess how effective my instruction has been.

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## Metacognitive Variables, Problems, and Solutions

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I think of metacognition as "second order" thinking about one's thinking. It is the reflective cognition about one's own "first order" cognition. Some writers have referred to this type of cognition as "higher order" thinking, as it seems to appear consistently in the documented thought processes of experts. But the metacognitive reflections during activities such as problem solving are not always helpful; they may distract and diminish the thinking that could be directed toward productive problem solving. The challenge of science educators is to teach students to use metacognitive thinking productively.

### Metacognitive Variables: Strategy Variables, Task Variables, and Person Variables

Metacognition has at least three large classes of variables that help us to distinguish how it works and how to adapt instruction to assist our students. They are: strategy variables, task variables, and person variables (Narode, 1987).

Most of the literature on metacognition is comprised of studies of reflections about the strategies experts and novices use to solve problems. The real-time conscious reflection about the various strategies that are considered moment-to-moment during problem solving is critical for the iterative process of solution-path evaluation and self-regulation. Some of these factors include: time management; selection of heuristics, templates, and algorithms; reasoning choices such as deductive, inferential, and analogous reasoning; selection of the different means and media of problem interpretation, representation and communication; selection of resources; solution confidence and checking strategies, etc.

Two other important considerations for metacognition have to do with the beliefs that the learner has about themselves with respect to the task at hand and their abilities to manage the task. These beliefs are the background and baggage that the learner brings to the learning activity. The "task variables" are the metacognitive reflections that the learner acknowledges about the problem posed or the learning situation generally. These are thoughts about previous experiences with similar tasks, analogous or not, and both positive and negative. It may be manifest with statements such as: "I remember this. This is a rates problem." In earth science class a student might remark: "I know that the barometer tells if the weather is going to worsen or clear, but I can't remember how."

From the previous example, we note that reflections and beliefs about the learning task are closely related to beliefs the learner has about themselves with respect to those tasks. Students may feel confident about themselves in various learning contexts or they may feel apprehensive, alternately enhancing or retarding their learning of science.

### Problems with Metacognitive Skills Training

Having identified how confident experts think and feel about their thinking, educators and curriculum developers may be tempted toward a path of direct instruction on these

very issues. Instruction may offer explicit descriptions of various strategies for representing and solving classes of problems including the use of inventories to help students evaluate the "type of learner" they are such as "auditory, visual, and kinesthetic", or if they are "linear or non-linear" thinkers, "right-brained or left-brained" etc. Students are also given opportunities to reflect on their confidence and feelings as learners of science usually in the form of surveys and journal writing. The instructors may even model their own approach to tasks and the strategies used with them as well.

While some of these activities may help some students, there is a very real problem that students will identify the content of the instruction as the goal of their learning. They may learn about the process of metacognition, while missing the opportunity to engage in the process of metacognition --- and to engage in the process in progressively more effective and constructive ways.

Finally, there is the problem of time away from the learning of content. There are important ideas for students to learn in the sciences beyond the psychology and technique of metacognitive skills training. Making the time for teaching both requires creative instruction.

TAPPS, "Think-Aloud Pair Problem Solving": A Solution for the Problem of Teaching Metacognitive Skills And Content Knowledge

One effective model for teaching metacognition and content is the think aloud pair problem solving [TAPPS] method of Whimbey and Lochhead (1985, 2000) which is itself modeled after the clinical interviews used by Piaget (1971). The approach requires that one student solve a problem by reading it aloud to the other student (the listener) and verbalizing all thoughts on the problem as they occur. The problem solver does all the writing and all of the talking about the problem. Meanwhile, the listener must suspend solving the problem so that complete concentration and attention is devoted towards understanding the problem solver's solution. By encouraging students to verbalize their thoughts, they are forced to examine their ideas as they communicate. They must evaluate those ideas in the light of another person's interpretation of what they are saying. Requests for clarification and repetition often help students to catch and correct their errors as well as helping to reinforce ideas that they may have held only tentatively. It also forces students to work more slowly (carefully) than they would without a listener, and it requires a much more linear thought process since oral communication is necessarily linear. By exchanging roles of problem solver and listener, students have the opportunity to learn the related skills of problem solving aloud and listening for meaning. Critical to the process is the insistence of teachers that the listeners describe the solutions instead of the problem solver.

The aforementioned metacognitive variables are addressed with this technique in the following ways: the discussion of solution paths with the larger class exposes various strategies and their justifications; the tasks may be viewed differently by different pairs, but success with the tasks may be generalized beyond finding the answers themselves to understanding the various solutions and deciding which of these they like best and why.

Finally, the confidence one feels for being a learner comes from the recognition of what one has learned. This recognition is manifest through communication to another person, whether through explanation, argument, or teaching. Nothing is more affirming to a person than being listened to and knowing they are heard.

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## Thinking about Metacognition

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I've been thinking a lot about metacognition lately, since I'm hosting a Teagle-funded Collegium on Student Learning that will focus on metacognition; our hope is that participants will get a good overview of recent research on student learning, particularly on metacognition, and then ask questions about their own teaching practice and ultimately make changes. We want our ACM faculty to enact the metacognitive practices we'll be studying in the Collegium—that is, to think reflectively about their teaching, to evaluate current practices against new and evolving evidence, and to make adjustments.

When I describe the plans for the Teagle Collegium to people, they invariably ask, "what's metacognition." My simple answer lately has been that it's "thinking about our thinking." And that, of course, involves many layers of complexity: in order to think about my thinking, I need a certain level of awareness, an understanding that I could be thinking in other ways or that my thinking has been influenced by various factors. I also need some sense of myself as a rational person capable of composing arguments that may be valid or faulty or partially correct and subject to revision. To think about my thinking, I have to become aware of what I believed yesterday and what has changed today, and what might happen tomorrow; that is, I can't cling to some notion of a context-less world of brute facts that appear obviously and unalterably to me and everyone else. And, if I'm going to talk about banjo playing or soccer or the wines of Languedoc, I'll need some sense of how I fit into the conversation: I should recognize the limitations of my knowledge about banjos, my passionate non-playing, somewhat intricate knowledge of soccer, and my participatory, reasonably advanced but by no means expert appreciation of wines from Languedoc. That is, I need some sense of what it is to think as an expert.

As I think about metacognition these days as an administrator, I realize how important the concept was to me in the classroom—even though I would not have invoked the term to describe my practice. Let me explain. For more than 20 years, I taught literature, mostly English literature, specializing in Shakespeare. In most of those classes, my chief goal was to help students find a way to make sense of literature, to not simply take my word for what the texts meant but to actively shape interpretations and to participate in the give-and-take of interpretation. I especially became interested in the question of authority. That is, how do interpretations become authoritative? How do students offer interpretations of a text that are both informed by authoritative traditions of criticism and backed by evidence from the text, shaped by their own experience but also convincing to others? It's a complicated question, one that depends a lot on theories of knowledge that invoke epistemologies of constructivism, notions of interpretive communities, and, perhaps most of all, complex understanding of our ability to think about our thinking.

As a classroom teacher, I was especially interested in how technology, particularly online discussion boards, could help in the process of teaching metacognition—and, overall, to help students develop interpretive authority. In work I did in the Carnegie Academy for the Scholarship of Teaching and Learning, I analyzed the work that my students did in

response to an assignment I made in my Shakespeare seminars that had students posting responses to plays before we discussed them in class and then after classroom discussions. I was especially interested in their ability to reflect in meaningful ways about where the discussions had gone, how their opinions had changed, and what had shaped their interpretations. (Asynchronous discussion was especially helpful for this because it stretched out the conversation and left a written record.)

That is, I was especially interested in students' metacognitive abilities and believed that learning to be a scholar of Shakespeare (that was, after all, part of the task) involved the ability to shape interpretations and to respond to other readings. I became more attentive to the ways in which our discussions included elements of reflection and self-knowledge—being able to step back from the give-and-take of the classroom to understand one's role in the shaping of knowledge. Even as I was leaving the classroom, I was shaping a theory that the most successful students in my Shakespeare classes were not simply those who wrote the best papers (often a measure of learning in literature classes) or who talked the most or could get good grades on factual exams about the plays—but those who learned best how to interact with the various interpretations shaped in the class and to understand the moves they had made as interpreters. That is, on some level, I was interested in metacognition.

There's a lot more to say about this, and I'm still struggling to complete various projects that discuss my use of the online discussions, my sense of authority in classroom discussions, and broader issues of social pedagogy. I look forward to learning more about metacognition from the disciplinary perspective of the geosciences—and in interacting with colleagues who will no doubt embody in eloquent and enlightening ways that central principle of thinking about our thinking.

## Metacognition: Thinking about Thinking and Learning

Dexter Perkins, Department of Geology and Geological Engineering, University of North Dakota

Starting in 1948, Benjamin Bloom and coworkers developed a classification scheme for educational goals and objectives. They identified three "domains" (kinds of learning): the cognitive, the affective, and the psychomotor domains. The cognitive domain involves knowledge, and all kinds of thinking, from rote memorization to complex analysis and synthesis. The affective domain involves attitudes, feelings and emotions that may hinder or promote learning. The psychomotor domain involves physical/motor skills – and will not be discussed further here.

For many years, as I sought to improve teaching and learning in my classroom, I focused on the cognitive domain. My belief was that if I could just find the correct way to "teach," students would effectively "learn." My unrecognized assumption was that learning simply involved thinking – that it was all a cognitive exercise – and so all I had to do was to get students to think. During the past four or five years, however, I have come to realize that the #1 barrier to learning is not cognitive, it is affective. Beyond that, however, I have realized that for students to become better learners, they must be self-reflective learners, they must be intentional learners, and they must care about improving their learning. So, we need to encourage them to think about their thinking and learning, to practice different learning skills, to be critical of themselves, and to try new learning strategies when old ones do not work. If we want them to improve their learning skills, we need to have them focus on thinking about learning and learning to think. This is metacognition.

A good summary of what constitutes metacognition comes from Wirth and Perkins (Learning to Learn, 2007 and later):

Intentional thought about one's own thinking (metacognition) is generally regarded as an essential component of successful thinkers and learners. Studies show "experts" constantly monitor their understanding and progress during problem solving. Critically, their metacognitive skills allow them to decide when their current level of understanding is not adequate. This type of planning, self-monitoring, self-regulation, and self assessment not only includes general knowledge about cognitive processes and strategies, but also appropriate conditions for use of those strategies, and general self-knowledge. Research suggests that metacognitive skills cannot be taught out of context. In other words, one can't just take a course on metacognition. You need to learn it and apply it within the context of disciplinary content. As you are learn, you should engage in constant questioning (e.g., What am I trying to accomplish? What is the best strategy for learning? How is my progress? Did I succeed?). This sort of self-monitoring and reflection not only leads to deeper and more effective learning, but also lays the groundwork for being a self-directing learner.



So, how do we promote metacognition in the classroom? Ay, there's the rub. The goal is to make metacognition a standard part of what goes on in a class. Fortunately, there are a number of strategies that have already been proven effective, although not all were developed specifically with metacognition in mind. Some of the strategies that I have employed include:

- \* Having students read a learning document, such as *Learning to Learn* (Wirth and Perkins) that discusses how learning skills are developed and . . .
- \* Making them responsible for learning what is in the document.
- \* Using knowledge surveys to encourage students to think about what they know, don't know, and what they can do about it.
- \* Having students keep learning portfolios and . . .
- \* Having them review their learning portfolios and writing critical essays about themselves and their learning.
- \* Having students follow exams or other assessments with self-reflective essays about what worked for them and what did not work.
- \* Using Small Group Instructional Diagnosis in the class room so students can provide meaningful feedback on what is helping them learn and what is not.

Other approaches that I have not used might include (ideas from Ed Nuhfer):

- \* Having students develop learning philosophies.
- \* Employing student management teams to probe the process of thinking and learning ongoing in the class.
- \* Involving students in the design of rubrics used for their assignments.
- \* And I am sure there are many others . . . and I would like to learn about them at the workshop.

When I first started some of the things above, I was worried that students would object. I expected some to ask why we didn't just focus on mineralogy or petrology or . . . instead of wasting our time talking about learning philosophy and thinking. That has not happened. In the four years that I have been focusing on helping students develop metacognitive skills, not a single one has complained. More important, many have told me that it is very valuable and they wish they had been forced to think about learning a long time ago.

## Using Self-Regulation to Develop Metacognition of the Scientific Enterprise

Erin E. Peters, Science Education and Educational Psychology, George Mason University

In studying science, many elementary and secondary students learn the subject as a collection of facts and gain little or no understanding of science as a discipline. The adoption of metacognitive strategies has the potential to help students make meaning out of science content and to become self-regulated learners. Self-regulated learners are desirable in the K-12 education setting because they are able to take control of their own learning, and are poised to become life-long learners. Learners that are self-regulated show higher levels of strategy use (Pressley, Goodchild, Fleet, Sajchowski, & Evans, 1987; Weinstein & Underwood, 1985), intrinsic motivation (Ryan, Connell & Deci, 1984), metacognitive engagement (Corno & Mandinach, 1983), and self-reflection (Ghatala, 1986; Paris, Cross & Lipson, 1984; Kitsantas & Zimmerman, 2006) than naïve self-regulated learners. Overall, students who are self-regulated are metacognitively, motivationally, and behaviorally active participants in their own learning process (Zimmerman, 1989).

Metacognition can be defined as the executive functions that control actions or the ability to recognize thinking patterns and evaluate them (Weinert, 1987) and is a portion of the continuum of self-regulation. Metacognition is the ability to think about and evaluate your own thinking processes (Brown, 1987) and is a part of being a self-regulated learner because self-regulatory strategies provide the mechanisms for students to regulate their cognition and learning (Zimmerman, 1989). Metacognitive control is the decisions, both conscious and non-conscious, that we make based on the output of our monitoring process (Schwartz & Perfect, 2002). Metacognitive monitoring and control can be a useful tool in helping students to identify scientific thinking and to check their own thinking for alignment with a scientific way of knowing. Since metacognition and self-regulation are related, it is possible that self-regulatory processes can be useful in developing metacognition in students.

Self-regulated learning can be used as a non-didactic instructional tool to relate the aspects of the nature of science to students on a metacognitive level as students engage in scientific inquiry. A student who self-regulates should be able to think about and evaluate their ideas according to a scientific way of knowing. One reason that teachers as well as students have difficulty understanding the nature of science is their lack of exposure to the same inherent ways of knowing as a scientist (Hogan, 2000). Self-regulated learning strategies could provide a framework that can scaffold naïve views of the nature of science to more developed views of the nature of science.

Self-regulated learning diagram

Figure 1. Self-Regulated Learning

Corno & Mandinach (1983) have found that metacognitive engagement can be learned by training in self-regulation of learning. As described from a social-cognitive perspective, self-regulated learners enter three phases that are cyclically related: forethought,

performance, and self-reflection as illustrated in Figure 1 (Zimmerman, 2000). The forethought phase partially refers to analyzing tasks and setting process-oriented goals (e.g., asking students to organize the content they already knew about the inquiry problem). The performance phase includes implementation of the task and self-monitoring (e.g., asking students to conduct hands-on inquiries and to monitor their progress). The self-reflection phase refers to the use of standards to make self-judgments about the performance (e.g., students compare their activities in the inquiry against one aspect of the nature of science). Because students continue to cycle through the self-regulation feedback loops, when students enter successive iterations of the loop, they have more sophisticated forethought, performance, and self-reflection. There is evidence that attainment of high levels of academic achievement requires a self-regulatory dimension of competence in addition to basic talent and high-quality instruction (Zimmerman & Kitsantas, 2007).

From this theoretical foundation, a metacognitive prompts intervention (MPI-S) has been developed and tested experimentally with 8th grade students for 3 years. This intervention is based on a 4-phase developmental training approach from Zimmerman's work (2000) that includes observation, emulation, self-control, and self-regulation. Observation entails vicarious induction from a proficient model. Emulation is a duplication of the general pattern of the model. The self control-phase occurs when the student independently uses the strategy in similar contexts, and the self-regulation phase occurs when the student can adapt the use of the strategy across changing conditions by being metacognitively aware of his/her own learning. The intervention, Metacognitive Prompting Intervention – Science (MPI-S), consisted of metacognitive prompts such as examples, checklists, and questions for each of the chosen aspects of the nature of science. MPI-S was composed of examples for the observation phase, a checklist for the emulation phase, a short checklist and a few questions for the self-control phase, and questions eliciting student rationale for decisions for the self-regulation phase.

Students exposed to the intervention showed statistically significant higher levels of content knowledge and knowledge about the nature of science than students not exposed to the intervention. Effect size was measured by Cohen's  $d$  for the content measure and the nature of science measure. The effect size for the content measure was  $d = .5$  and for the nature of science measure was  $d = .8$ . In addition, qualitative findings revealed that the experimental group made choices based on evidence in the inquiry unit. However, the control group differed to authority, even when it conflicted with the evidence presented in the activity. When asked what it was to think scientifically, the experimental group responded that the modules taught them that scientists use their prior understandings to explain new phenomena and that their explanations require a large amount of detail.

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## Thoughts on Metacognition

William Rose, Michigan Technical University

I am a participant who has very little education training, but I have tried to teach anyway. What I know, I have learned on the hoof, and I don't know any of the jargon, and have not formalized many of the concepts. I didn't really know what metacognition meant, although after it is explained, I think I know quite a bit about it. My experience in teaching has mostly been with graduate students, and I now realize that my ability to get a successful result from them very much relates to getting them to improve advanced levels of thinking (Wirth & Perkins, Table 1), whereas before I thought more carefully, I thought they were just poorly prepared in writing skills. I think the diagnosis of student learning difficulties is quite tricky, and I would like to improve this ability if I can.

It is clear to me that graduate school should be focused as much as possible on synthesis, evaluation and learning how to learn, whereas we often spend almost all our time with application and analysis. We spend a lot of time reading and dissecting scientific articles. One thing I would like to do is to have students do dissection of these articles by using and applying the concept of levels of thinking or significant learning. I think this would build some important comprehension and self knowledge, and maybe motivate them in a different way to see quality writing and communication. Maybe I can implement this idea.

When I do teach at the undergraduate level, I need help at communicating and developing advanced levels of thinking. It may be possible to do this by habit, but I tend to get distracted, and end up focused on the science details. I carry a strong feeling about my own learning that scares me in a way. I don't like to be told things and would much rather realize them myself somehow. This obsession embarrasses me, and I tend to try to hide it from students, but it is too strong to hide. It affects my teaching negatively, I am sure. I do not really know if all students are like me in this way. It would be good if a teacher could provide clues in a sly way that students could trip over and then apply, analyze, integrate and synthesize. Perhaps the best ones would resent this manipulation?

I feel a strange reversal happens with students when dealing with "mundane" computer skills. In these matters students are in some way at a higher level of thinking than I am. I would like to use this reversal to stimulate learning if I can, and feel intuitively that it could be powerful.

I hope to learn a lot from this workshop.

# Researching Transfer of Knowledge with Elementary Pre-service Teachers

by Sandra Rutherford, Department of Geography and Geology, Eastern Michigan University

As with all educators I would like the students in my class to understand what is behind the knowledge I am trying to impart upon them. I teach Earth Science to pre-service elementary teachers as well a methods class to secondary pre-service Earth Science teachers. With the Earth Science for elementary teachers class I have tried many techniques, from weekly vocabulary quizzes (memorizing because I figured if they could not remember what the word was they would not understand the sentence it was in), putting multiple choice questions in the PowerPoint and having the students hold up cards, and review podcasts to explain concepts that could be listened to repeatedly.

Before I became a professor in geoscience education I was a grade 8 Earth Science teacher in Colorado. Although I always told my elementary teachers stories about being a teacher and tried to give them ideas for activities that I did in my class I didn't discuss pedagogy too much with them since I figured this was the elementary methods classes' job. But about two years ago I started having the students do a DLESE project where they were asked to find an activity from the DLESE website that would satisfy a Michigan content expectation (Michigan, 2007); they do this for 3 different content expectations from each of the 4 standards. At the same time I started describing various misconceptions as suggested by Gallagher (2000) in the diagrams I showed in class or in the activities I did as a demo. I also told them they should be keeping these 12 DLESE activities by cutting and pasting them into Word and saving them in a folder on their computer. The students started asking more questions about the content we were discussing but still I didn't think what I was doing was really helping until I started a transfer research project with my colleague in chemistry, Amy Flanagan Johnson.

Transfer of learning is described by Mestre (2003) "to mean the ability to apply knowledge or procedures learned in one context to new contexts." We did a pilot study to determine if the students in our classes were able to make connections between the content of the two courses. We gave both of our classes (she teaches chemistry to elementary teachers) three surveys; an introductory survey which included student demographic information and their expectations for the course. A content survey that reviewed content that was covered in both classes in the style of the New York Regents exams. In this survey we also asked them to explain their answers to the questions and list where they learned the information to answer the questions. And a final survey that asked the students to reflect on what they had learned and what they valued from the course.

I will not repeat the results from the survey as this work has been submitted to a journal but I will say that what surprised me most from the study was that when the students were asked in the final survey these questions:

1. What do you think are the most important concepts, skills, and/or ideas that you learned in this course?
2. Why are the items listed in question #1 more important to you than others in the course?
3. How do you foresee yourself using these in your future education and/or career?
4. What do you think that your **professor** feels are the most important concepts, skills, and/or ideas that you have learned in this course (please list specific examples)? Why?

The students in my class listed answers which had to do with pedagogy (and mentioned DLESE) and misconceptions. The chemistry class also discussed pedagogy but more from a career point of view than from wanting to know how to teach the students, they did not mention misconceptions.

Final Survey (the question being answered is the number in front of the response)	
Earth Science responses - pedagogy	Chemistry responses - pedagogy
1. "how to take a subject and make it a hands on experience that is fun and enjoyable for children"	1. "The most important skills would be how to better teach chem. – loved the examples and demonstrations given in lab and class – also the lab manual will be a good resource for my future classroom."
2. "B/c we can find all the facts on our own – but his helps us actually prepare for teaching in the classroom"	2. "This will help me in the field – I have already learned science. I need professional skills now."
3. "Yes, I see myself using especially [sic] DLESE to help me find activities to use in my classroom"	3. "Because if I can think like that than I can teach my students to think like that and enjoy science."
4. Being able to apply everything we learned through experiments and teaching the important information not just baking soda and vinegar volcanoes"	4. "teaching how to teach, that is the reason we are here, teaching students the importance of practicing to remember is a huge important idea."
Earth Science response - misconceptions	
1. "critical misconception explaining (angle of sunlight on the earth)"	
2. "I feel fixing a misconception opens the door for a better understanding"	
3. "I plan on involving my students in the classroom to learn their misconceptions. Afterward I will teach them why tier misconception is wrong."	
4. "I think the most important skill would be that we learn and make sure that the students have no misconceptions."	

Out of the 5 content questions the Earth Science students had a higher percentage of correct answers expect for one question.

Percentage correct from the 5 content questions *question where I did not use the term specific heat in class	
Earth Science	Chemistry
1. 81.6 %	1. 42.9 %
2. 84.2 %	2. 51.4 %
3. 23.7 % *	3. 31.4 %
4. 63.2 %	4. 45.7 %
5. 68.4 %	5. 62.9 %

This question used the term "specific heat" with reference to water and I never actually used that term in class instead I talked about how water had the ability to absorb heat and that it took longer to heat up. Something I need to rectify. However, the other content questions gave me the feeling after seeing their answers to the final survey questions that the students were motivated to learn the material in more depth because they were going to teach these concepts to their own students. When the students take Earth Science for elementary teachers they have not yet been accepted into the College of Education here at Eastern Michigan University. By putting more emphasis on pedagogy and misconceptions in a class that was supposed to be primarily a content class I believe their understanding improved. Mestre (2003) points out that context which includes things that are relevant to the core concepts being taught also includes a reason to learn the concepts. "How important is it that the



learner believe he/she will actually need the knowledge in “real life” as compared to just being able to pass an exam?” Therefore, if the students in my class realize that they need to teach little children this material and they start to think about how they are going to do this, it motivates them to want to understand it so they will not pass on their own misconceptions to them.

I have provided a more comprehensive list of references about transfer research from our paper (which has been accepted to the Journal of College Science Teaching) below for those that may be interested in this topic:

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## Metacognition Essay

Jeannette Sablock, Salem State College

I broadly define metacognition as a term which encompasses many different ideas about the mechanics of how students learn, how they understand how they learn, and how they use that information to enable themselves to be better learners. Whether acknowledged or not, I think all teachers think about metacognition when preparing course materials, often using themselves as a model. I've come to realize that modeling student learning on my learning style is not useful since I am a scholar by inclination and occupation, unlike most of my students. A more useful approach is to require students to complete an in-class or online learning style survey early in the semester. Students enjoy the process and I gain a better understanding of what kind of learners are in the class. With the availability of useful resources such as those from SERC's Cutting Edge Collections (which I browse & borrow from often), finding a useful resource is easy. I always start with these materials when I'm looking for a project or an idea and either use them directly or modify them to suit my class. Understanding how students learn is critical to setting and accomplishing our goals as educators. Helping students understand themselves as learners puts them on the path of lifelong learning, one of the primary goals of general education.

I teach metacognition by attempting to make student learning and progress visible to them. An example of what I mean by that is a simple little exercise I have students do the first time they work with the polarizing microscope. After an introduction to the microscope using a modified version of Jane Selverstone's excellent power point presentations Optical Mineralogy In A Nutshell (available on John Winter's website and used with permission), I put a list outlining the various parts of the microscope on the board and have them go to a scope and stick labels in the appropriate places. I can then check their work on the spot, correct errors and move on to using the microscope. I also provide opportunities for students to compare themselves to their classmates through in-class projects, in part to show them that what I expect them to learn is learnable by many of their peers.

One of our goals as teachers is to discover what and how students are or are not learning; their goal is often to hide that information from us. Assessing student learning therefore, requires a certain amount of trust on the part of the students; trust in both their fellow students and in their instructor, and a bit of trickery on the part of the instructor. With trust you can generate meaningful responses to the often pointless "Do you have any questions?" question. With trickery, in the form of in-class projects and reflection questions, you can learn what your students are learning and what they are confused about.

An aspect of metacognition which I think would be especially useful to me concerns helping students develop into what Karl Wirth described in his essay as independent learners. Many of our students are the first generation in their families to go to college, and many of them are dependent and timid learners. I'm defining timid learners as

students who are afraid to make connections from the material learned in one class to another, or to make 'best guesses' based on limited information. Other aspects of metacognition which interest me include the idea of building memory hooks, and student reflections on learning. The business world trivializes the idea of memory hooks as a tool for remembering clients' names, but I think memory hooks are critical for learning, especially for learning complex information. I try to compress the process of hook forming and layering to a sequence of quiz, related lecture(s), in-class projects and reflection questions; a process which I think falls under the widely used term scaffolding (Jamie McKenzie, 1999). For example, here's the sequence I use for introducing the topic of phase diagrams to a sophomore level Mineralogy class. 1) A brief introduction (1 to 2 slides), at the end of a power point presentation on an unrelated topic, the week before we start the topic of phase diagrams. 2) A quiz, to set the hook, on the Phase Rule before a more in-depth lecture on the Phase Rule. 3) A lecture with some interactive material included followed by a short in-class assessment with a reflection component, to evaluate how well they understood the material. 4) A short lecture adding another component to the previous material followed by an in-class project for review, and to guide them through some of the mechanics outlined in the lecture. Near the end of the period their answers are discussed. The main concepts are reviewed the next week along with another project which is started in class and finished as homework. Students succeed with the scaffold. The critical question is, can they become independent learners and succeed when the scaffold comes off?

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## iCognition

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*Abstract.* To what degree can technology be used to facilitate research on the value of metacognition? Here we consider how to implement metacognitive training in a course on atmospheric sciences using two web applications. One is used in-class and the other for homework. Early results are discussed.

I remember once finishing a lecture on the why particles are distributed in three modes in the atmosphere. I used an image, brilliantly developed years earlier by Prof. Kenneth Whitby of the University of Minnesota showing a plot of the tri-modal distribution of particle number versus particle size (Figure 1) as I felt it embodied the essence of what I was trying to convey that hour. To be sure I was pleased with my lecture, detailed yet full of examples and relevant examples working to describe how physical processes in the atmosphere would be expected to produce three distinct sizes of particles. The graph had served to end the lecture with the scientific major chord that would have made Beethoven proud.

I stood and turned to the class and asked for questions. There was a long silence, which I assumed to be a time of reflection, with the students absorbing the lesson and constructing their own understanding. Then, just before time was up a fellow in the front row raised his hand and asked, "I see the three mountains in the picture, but I don't understand which way the wind is blowing."

It is the only time in my 30 years of teaching that I swore at a student...

The relationship of this story to metacognition is embodied in that rapsallion's response. Students often think they understand what is being taught but it is not uncommon that that are wrong. Metacognition is, first, the process of students, independent of

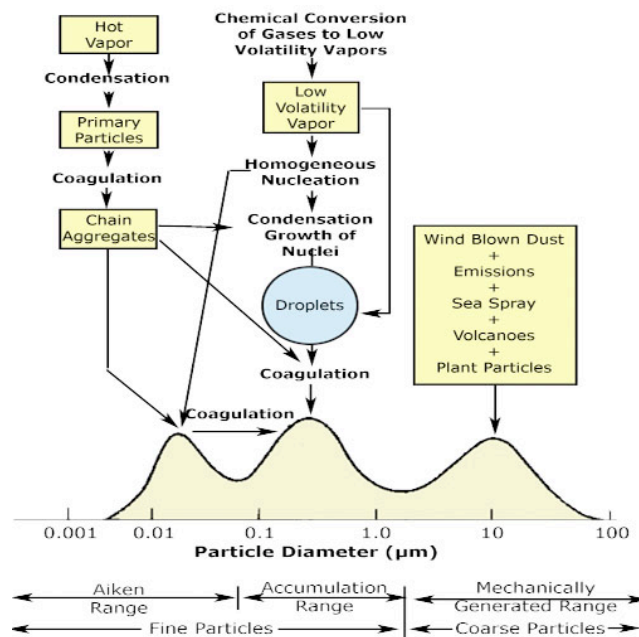


Figure 1. Frequency distribution of particles in the atmosphere by size as developed by Whitby (1978).

quizzes and tests, understanding what they understand. Second, once realizing their understanding is flawed it is the process of students independently making adjustments in their learning strategies to improve their learning in subsequent opportunities.

It is not something taught in any science class I ever took.

Metacognition can also happen with a wide range of granularity. On the scale of a semester, for example, many instructors design a first exam that is somewhat harder than the rest. This serves to get the attention of those who thought they understood the material and took meager effort to prepare for the exam. Having made that mistake once some will change their study strategies and devote more time and energy to the process by the second exam. Here a simple way to stimulate metacognition is to meet with those who perform poorly and ask them if they were surprised by their grade, why they think they did poorly, and how had they studied for the exam leading to questions about what strategies they will want to adopt to prepare for the next exam.

The literature is ripe with articles on metacognition, but scientists may find such literature obtuse and lacking in examples relevant to their discipline. So, at the risk of insulting the scholars of this field this article offers a short guide to metacognition. My goal is to give my opinion on why we, as geoscientists, should care about it; examples of how you might implement it in your classes and strategies for assessing whether it was worth the effort. My motivation for exploring this issue, I will admit, has not been entirely altruistic (i.e. to better the learning outcomes of my students) but more to explore how to build these principles into the web applications I am constructing for large classes. I offer these tools as one example for how to implement metacognitive principles in lecture and in homework assignments.

## What is Metacognition?

As a scientist I do not feel qualified to define what metacognition is or isn't. Fortunately for me the topic has been well articulated by others, including on this site. In *How People Learn* (NRC, 2000) metacognition is identified as one of three core learning principles for the enterprise of teaching. They state

"Integration of metacognitive instruction with discipline-based learning can enhance student achievement and develop in students the ability to learn independently. It should be consciously incorporated into curricula across disciplines and age levels."

Yet, despite its perceived importance it is possible that a broad spectrum of science instructors at colleges and universities are unfamiliar with how to implement metacognitive instruction in their courses. Moreover, even if motivated to use metacognition instruction, it remains a "fuzzy" concept (Wellman, 1983) with many authors offering variations on the basic definition.

Metacognition has been defined to consist of the knowledge and regulatory skills that are used to control one's cognition (Schraw, 2001). Schoenfeld (1987) summarized that metacognition encompasses three categories of students' intellectual behavior:

1. Their knowledge about their own thought processes (Is it accurate?)
2. Their self-regulation of knowledge (Do they track their learning actions?)
3. Their beliefs and intuitions (What beliefs/preconceptions do they bring to class that will shape their learning?)

Accepting that the integration of metacognitive instruction is an important and useful component of course design in higher education, instructors are still left to identify methods to achieve this goal in their own classes.

## What's in Metacognition for Me?

Many students arrive in our classes with good study habits and a desire to learn. They have, at some point, constructed strategies for adapting their learning to new situations and disciplines. But other students, and particularly in the survey courses required of non-science majors, bring to class a preconceived view that science "doesn't come easily" to them and, save for protecting their precious GPA, they have little incentive to change that opinion. Some of these students complain that they are doing well in their other topics but science provides a mental block. This self-perception, coupled with their non-voluntary conscription in the science class offers them little hope for performing well in the course. These are the students for whom we earn our salaries.

Arguably we could ignore them and ignore their grouching about the requirement and the course (a popular decision as many of the instructors for these courses have likewise been conscripted into participating). But for those who are passionate about their discipline it is both inconceivable that students don't share their enthusiasm and an enigma that students do poorly on their exams. It is, in fact, confusing why some students cannot do well on the exams and quizzes. It is for these latter students that metacognitive skills can play an important role and, arguably, it is through the administration of metacognitive training that instructors may find the best hope for overcoming the preconceptions students carry into class.

A simple step in metacognitive training that I've employed is to require all students who do "poorly" (definitions are subjective) to meet with me after the first exam. In these individual meetings I try to learn about the student's history and how they perceive they are doing in their other classes and their attitudes about learning. I've used these opportunities to ask how they studied for the first exam and work with them to construct other strategies. As a result of this I began to compile a list of strategies that students

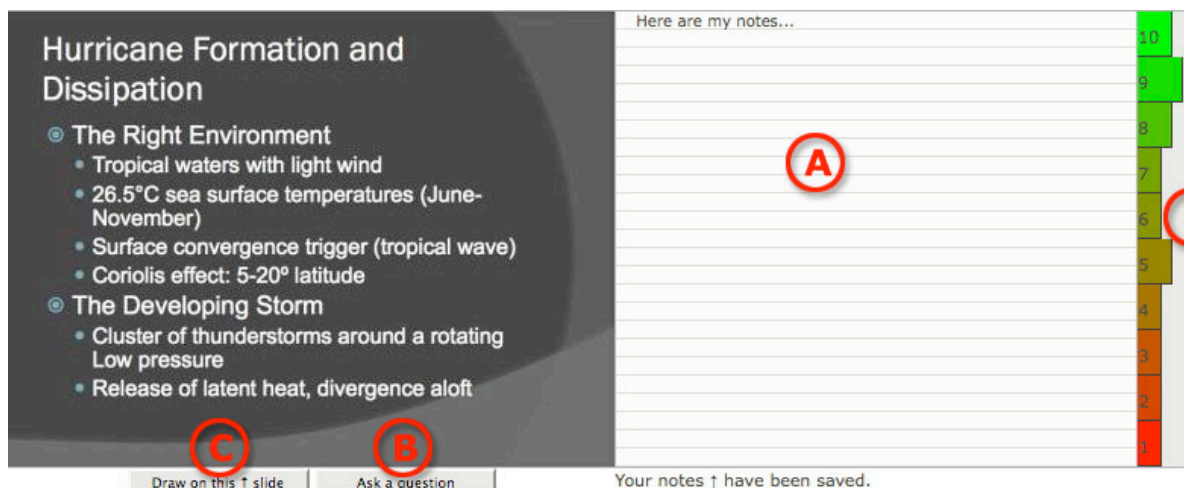


Figure 2. Screen shot from one pane of LectureTools showing (A) note-taking area, (B) question-submission button, (C) draw-on the instructor slide and (D) student self-assessment of "confidence" in understanding. [from <http://www.lecturetools.org>]

thought would be useful. On top of that I spent an excellent semester on sabbatical at the Carl Wieman Science Education Institute at the University of British Columbia in Vancouver where faculty and science educators meet weekly to discuss a weekly reading on topics germane to science education. Here articles drawn from the literature were discussed, some of which focused on the issue of metacognition.

My interest was to take the lessons learned from my own experiences and those gleaned from the literature and incorporate them in two web applications that I was developing for use in classes at the University of Michigan.

## Using Web Tools to Study Metacognition

Over the past four years I have been designing, coding, and evaluating systems that use Internet devices to expand peer discourse in introductory science classes. Two systems have evolved, the first, 'LectureTools' (<http://www.lecturetools.org>), began as a framework to research new methods for expanding in-lecture discourse by engaging students in text-based, image-based and simulation based responder questions. The second, XamPREP (<http://www.xamprep.com>) was my attempt to rethink the design of on-line textbooks by making them more inquiry-based. Neither tool is presented as a solution to how to integrate metacognitive training into class, both do, however, represent a framework in which both new methods and approaches can be tested.



## In-Class Tools

The original intention was to develop a web-based student response system (SRS). However, as students and instructors used (<http://www.lecturetools.org> 'LectureTools') they offered ideas for how it could be made more useful and easier to use. The system evolved rapidly through ad hoc trials coupled with rapid prototyping.

Today 'LectureTools' has evolved to provide a range of student response options plus it allows students to take notes synchronized to lecture slides, draw on and save the instructor's lecture slides, pose clarifying questions that can be answered asynchronously during class or after class and self-assess their understanding during lecture (see Figure 2). The latter aspect ("D" in Figure 2) is an evolving effort to facilitate student introspection during lecture. While still a research tool the concept was that students should be able to indicate their self-assessed "confidence" with the material being presented. In principle this allows students to mark parts of the lecture where they are less self-confident and instantly get feedback on how the whole class is voting (the "confidence" bars update every few seconds). Moreover the instructor also receives this information in real-time and can use this information to revisit topics during lecture or subsequently.

## Out-of-class Tools

One motivating reason I wanted to redesign the textbook was students freely admitted that a large majority rarely opened the book save for the week before an exam. This was especially true for students who had scored poorly on exams. My goal was to force reading more in concert with lecture and the mechanism I used to achieve this required a redesign of the textbook.

First, the textbook is delivered in an inquiry-based format where I can easily select about ten multiple choice questions before each lecture and assign them to be completed before lecture begins. As the student tries to answer these questions they are immediately directed to the place in the book where they can begin to find the answer. This model 1) forces students to consider concepts germane to lecture before lecture and 2) focuses their reading to the areas of the text that I consider particularly important. A hidden agenda is to provide a model for weaker students to instill more consistent and synchronized study habits.

At the same time I wanted the online textbook to be more than just a textbook online. I wanted it to take advantage of the communicative power of the Internet by integrating tools for self-assessment and query. Figure 3a illustrates an initial screen in a pre-lecture quiz. Figure 3b illustrates the screen when the student gets the question correct. Notice it now offers both the opportunity to self-assess their level of confidence in understanding the question and answer and a link to pose a follow-up question that is sent to a representative of the class (chosen by the instructor). Figure 3c shows the graph returned after entering a confidence factor in which the cumulative votes for the whole class are returned. These graphs are also available to the instructor who can review which questions caused the poorest confidence and can choose to use this feedback to guide lecture discussion.

The figure consists of three screenshots of the XamPREP interface, labeled (a), (b), and (c).

**(a) Initial screen:** The interface shows a quiz question titled "The most abundant greenhouse gas in the earth's atmosphere:". The options are carbon dioxide, nitrous oxide, water vapor, methane, and chlorofluorocarbons (CFCs). The "water vapor" option is selected. A "Check my Answer" button is visible. The background image shows a snowy landscape with a sun. The title "WARMING THE EARTH AND THE ATMOSPHERE" is displayed.

**(b) Feedback screen:** The interface shows the correct answer, "water vapor". A confidence scale is provided, ranging from 1 (Barely) to 5 (Totally). The student has selected 4. A "Next Question" button is visible. The background image shows a snowy landscape with a sun. The title "WARMING THE EARTH AND THE ATMOSPHERE" is displayed.

**(c) Confidence distribution graph:** The interface shows a graph of the confidence distribution for the question. The x-axis represents the confidence level (1 to 5), and the y-axis represents the percentage of students. The distribution shows that 1% of students chose 1, 1% chose 2, 11% chose 3, 28% chose 4, and 58% chose 5. The total number of responses is 134. A "Still confused? - Search clarifications others have requested." link is visible.

Figure 3. Screen shot from XamPREP showing (a) presentation of one of the questions in a pre-lecture quiz, (b) feedback when the student answers correctly, and (c) additional feedback when the student indicates their level of confidence in understanding the question and answer. [from <http://www.xamprep.com> ]

## Models for Implementing Metacognition

A model for how to implement metacognition is presented on the SERC website<sup>1</sup> based on the work of Lovett (2008). Restated, the examples offered are to consider building "wrappers" around lectures, homework and exams that will lead students to monitor and adapt their learning strategies. Focusing first on lectures it is suggested that instructors begin lecture by encouraging their students to think about the key points of the lecture as they listen and take notes. At the end of the lecture, ask the students to write what they think the three most important ideas of the lecture. After they hand those in, the instructor should reveal what they consider to be the three most important ideas from the lecture.

It has been suggested by Lovett (2008) and others that one model for teaching students to monitor their learning and to adapt their strategies to learning challenges is through use of "wrappers." In lecture, for example, it is beneficial to "wrap" the lecture - or a subset of the lecture - with a question before and after. One example would be to ask students to assess their ability to, say, read maps, then give them a challenge that requires map reading and ask them afterwards to assess their ability to perform the task assigned. Through this process of self-assessment, concept challenge, feedback and post-assessment students will often see that their level of understanding is less than they expected. Subsequent discussion can help the student rethink the concept and challenge the beliefs/preconceptions they brought to class.

Success has also been shown at reducing the granularity of assessment to the sub-lecture level. One alternative is to offer "mini-lectures" that are wrapped inside a concept question. Palinscar and Brown (1984) also propose the use of "reciprocal teaching" wherein students interact verbally to increase their understanding as part of the "wrapped" mini-lecture. This approach resonates well in science education where Mazur (1997) has introduced "peer instruction" to stimulate verbal interactions in science classes. Peer instruction has been demonstrated (Bair et al., 2007; Crouch and Mazur, 2001) to be effective in increasing student understanding.

The "mini-lecture" model (Figure 4) suggests the following steps:

1. Break lecture into smaller units and, as appropriate, pose a concept test first that asks both a concept question and/or queries the students to assess their understanding of the concept.
2. Once they have answered you ask them to defend/discuss their answer through discussion with others in the class.
3. At this point you may ask them to edit/repost their answers to questions from (1) and/or open a discussion with the class to answer questions that have arisen.

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<sup>1</sup> [http://serc.carleton.edu/NAGTWorkshops/metacognition/teaching\\_metacognition.html](http://serc.carleton.edu/NAGTWorkshops/metacognition/teaching_metacognition.html)

4. Optionally, at the end of this mini-lecture you may ask a follow-up metacognitive question like "Now that you have completed this segment, how quickly and easily do you think you can solve similar problems?"

The mini-lecture typically transitions into a new concept and the cycle is restarted. Clearly it would become onerous to all to ask metacognitive questions multiple times in a lecture so it is suggested that step (4) be offered only occasionally and most effectively on the more challenging concepts. We speculate, but have yet to assess, that introduction of these techniques earlier in the semester will help condition the students to critically assess their understanding throughout the semester.

The "wrapper" for the mini-lecture will be to ask students to self-assess their understanding of the topic prior to the content quiz. This is followed by a concept challenge. As they answer each question they are asked to self-assess their confidence in their answer. The solution is posed and students are asked to assess how well they did and, if incorrect, where they believe their logic was flawed. The value of the technology here is to document answers and provide a reasonably easy mechanism to construct and deliver questions and surveys.

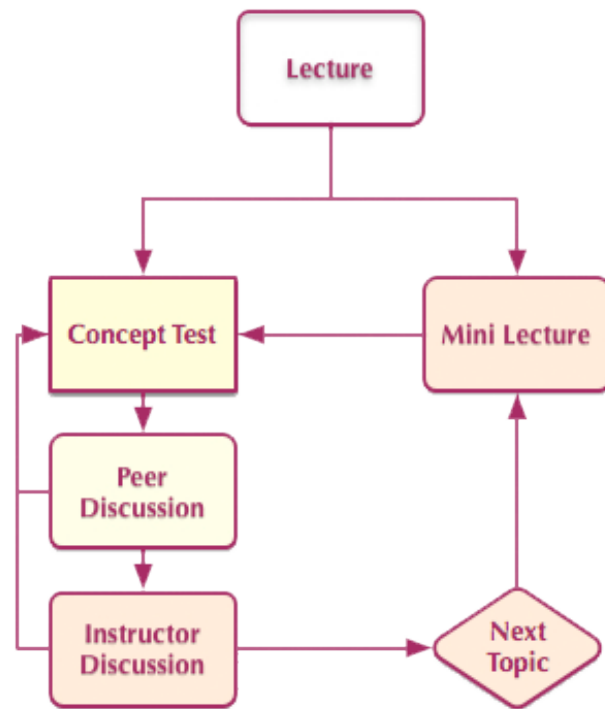


Figure 4. Model for Mini-Lectures based on Peer Instruction techniques (Mazur, 1997).

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## **Reasoning and Learning with Analogies: Making Metacognition “Natural”**

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By show of hands, roughly 70 % of the students in my general education course for non-science majors believe scientists and non-scientists think differently. If students believe that scientific thinking is somehow different from the way they think, learning science must, for them, represent a daunting challenge. Faced with this obstacle, students might rationally choose to attempt to learn science by rote memory, a strategy at odds with most instructors' desire to help students develop higher order thinking skills. If students are provided the opportunity to reason by analogy, they may recognize that everyone thinks like a scientist.

According to linguists and cognitive scientists, the human mind specializes in learning through analogies (Lakoff and Johnson 1980, Hofstadter 2006, Pinker 2007). Children do it (Goswami 2001). Even chimps draw analogies (Oden et al., 2001). Douglas Hofstadter writes in the introduction to his recent book, *I Am A Strange Loop*, "the bottom line is, every thought herein could be listed under analogies." Pinker (2007) expresses this in a different way, "to think is to grasp a metaphor". Part of the reason Hofstadter, Pinker and many other cognitive scientists (e.g., Gick and Holyoak, 1983, Blanchette and Dunbar 2002, Gentner 2003, Holyoak, 2005) believe analogy is a fundamental cognitive process is that drawing analogies requires some sort of similarity mapping of one concept on another, a process which lies at the heart of learning. As a recent example, many of us have been reading newspapers hoping to learn about the global financial crisis. We've learned that credit default swaps are like insurance policies and that the present global financial crisis is sort of like the Great Depression, but there are important differences. Almost everything we've read about the financial crisis has been cast as analogies.

Geologists reason by analogy (Schumm 1991, Frodeman 1995). When Lyell coined the geologists' mantra, "the present is the key to the past", he tacitly expressed the central importance of drawing analogies in geological reasoning. Walther (1893)

stated, "the most satisfying genetic [genesis of] explanations of ancient phenomena were by analogy with modern geologic processes" (quote from Middleton 1973, p. 981). Airy (1855) described the "perfect" analogy between the earth's crust floating on the mantle and a raft of timber floating on water. Analogies remain prevalent in the most up to date geoscience literature as in a recent article, *Brazilian Analog for Ancient Marine Environments on Mars* (Bridges et al., 2008).

I include instruction and practice of analogical reasoning to help students engage in authentic geologic reasoning. We begin with everyday analogies, hopefully convincing students that reasoning by analogy is both familiar and natural. This approach is implicitly metacognitive. It is implicit in that students are asked to recognize the similarity between their everyday analogical reasoning and the assignments I give them to draw analogies between new concepts and their established understanding of similar concepts. The approach is made metacognitively explicit when we breakdown analogical reasoning into parts (Figure 1A) as suggested by Holyoak (2005). Each part is explained with examples from the everyday analogies the students draw. For example, retrieval may be exemplified by noticing the wings on a bat while mapping, the process of comparing similarities and differences, might lead to the conclusion that comparing hair on a bat to the on hair on a mouse is more meaningful than comparing

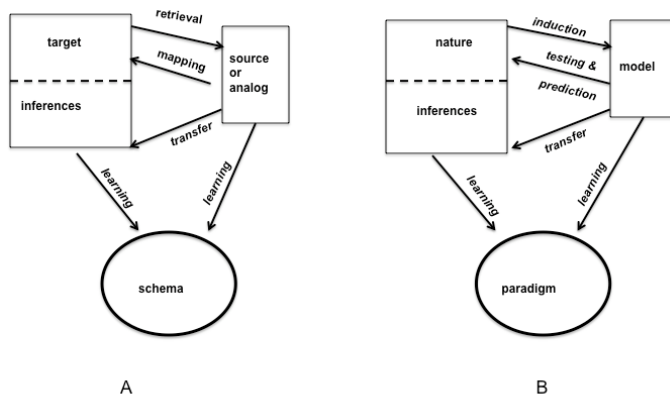


Figure 1. A) Holyoak's (2005) depiction of learning by analogy with a parallel representation of how scientists gain knowledge with models.

wings on bats and birds. While wings on birds and bats support inferences something about bats, the fact that bats and dogs share hair and, therefore, are both mammals supports many more inferences. We move from students' analogies about the

very familiar to students' analogies that will help them learn new concepts. For example, the average amount of time students spend in university is an analog for residence time of water molecules in the oceans. Later in the semester, the water cycle is an analog for the rock cycle. Characteristics of the rock and water cycles can be used to construct a model of the carbon cycle. At this point, students are building a scientific model based on the same elements found in analogies (Figure 1B).



QUESTION COMPONENTS	SCORING RUBRIC
<p>1. Write an analogy for _____*.</p> <p>You may include a drawing or diagram in your answer.</p>	<p>SCORING RUBRIC: Each analog will be categorized as relational, descriptive, trivial or other. Correct relational or descriptive analogs will be scored 1. The other category includes non-analogs.</p>
<p>2a. Make a list of two significant similarities between the target and the analog.</p> <p>2b. List two or more significant differences between the analog and target.</p>	<p>SCORING RUBRIC: Correct relational or descriptive similarities and differences will be scored 1. Incorrect relational or descriptive similarities and differences will be scored 0.</p>
<p>3. What questions about the target does the analog raise for you?</p>	<p>SCORING RUBRIC: We are not sure how the students in this study will respond to this question. We will attempt to score it on a basis of 1- has significant questions about the target and 0 - does not have significant questions about the target.</p>
<p>4. State a hypothesis based on one of these questions.</p>	<p>SCORING RUBRIC: We will score this as 0 - no hypothesis or hypothesis not related to the analog or 1 - hypothesis related to analog.</p>
<p>5. Test your hypotheses</p>	<p>SCORING RUBRIC: We will score this as 0 - no test or 1 - a reasonable test.</p>
<p>6. Based on what you know about the analog, what can you infer about the target? In other words, what does your analog tell you about the target?</p>	<p>SCORING RUBRIC: This will be scored as 0- incorrect inference(s), 1- correct</p>

Table 1. Scoring rubric for analogies. Many exercises involve fewer than six components. For example, students might be asked to take a given analogy and complete components 2, 4 and 5 or they might be asked to draw their own analogy and complete components 3 and 6.

At the beginning of the semester, students are not proficient at analogical reasoning about science. Quite naturally, they use non-scientific analogs for scientific concepts. For example, two cars crashing is the most common analog students use for subduction. To help students improve, we have to provide lots of practice with feedback. Students write analogies online using our online homework and course management system, LON CAPA. Their responses are downloaded into SPSS Text Analysis which we use to establish the most common answers. We have also developed a rubric for

scoring students' analogies (Table 1). We are still in the process of determining the validity and reliability of this rubric. If it is valid and reliable, then we will use it to measure students' ability to reason by analogy. Their reasoning would be determined to be correct when they can draw an analogy, recognize similarities and differences between the analog and target and either test hypotheses or draw inferences using the analogy. Students who can do this would be thinking and reasoning as scientists.

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## Teaching for Intentional Learning: How learning goals, learning skills, and feedback affect learning

I teach courses on cognition and instruction, educational research, and curriculum and instruction at Hampshire College, and have begun collaborating with Darby Dyar at Mount Holyoke College on a project to use visualizations in teaching mineralogy and geology.

I have specific skills I teach explicitly in my courses. My courses are inquiry-based and require a range of inquiry skills, skills associated with reading primary research literature (Wenk, Tronsky, & McNeal, 2005), and specific skills associated with any number of disciplines in which my students have interest. Because of the domain in which I teach (teaching and learning), my employment of a metacognitive approach to teaching is, itself, a little “meta” at times. When I teach about metacognition, I teach about teaching mental processes as the focus of instruction while I am making the mental processes required to do so the focus of my instruction. Sometimes it makes my head spin. More seriously, my overarching tactic, as with many who use a metacognitive approach, is to engage in co-construction of knowledge with my students, whereby I model strategies, scaffold my students’ practice of these strategies, give them feedback, and then turn over control of these operations to them. The explicit discussion of the strategies allows for consideration of other situations in which to use the strategies, and equally important, when not to. Such conditionalizing of the procedural knowledge aids in transfer of use (Bransford & Schwartz, 1999).

In this essay I will first talk about a set of ideas I teach in my course, “How People Learn” that my students and I find interconnect to build a powerful explanation of why some students are more engaged learners than others, and what we can do to improve learning for more students. Then I will take a preliminary look at the work Darby and I have begun on visualizations. It is this latter work that I most hope to improve through my participation in this workshop. Hopefully, I can tie the two pieces of the essay together.

### Intentional Learning and Learning as Improvement

The ideas we explore early on in “How People Learn” are about students’ implicit theories of intelligence, their goals, their behaviors as learners, their motivation, the intentionality they employ as they learn, and the specific strategies they gain when they are intentional learners. Dweck and Legget (1988) teach us that students believe either that intelligence is a fixed entity (you have it or you do not) or that it is improved incrementally. The former set of learners often develop performance goals, whereby they are most concerned with demonstrating they are intelligent by doing well on an assignment. When met with a challenge they might demonstrate maladaptive behaviors such as avoidance or helplessness. It is safer to have an excuse for not doing something than to do poorly and show you are not smart. The incremental theorists generally

develop learning goals, enjoy a challenge and work even harder when faced with a challenge. They see the opportunity to advance their learning when things are more complex than they first imagined.

Bereiter and Scardemalia (1989) show us that learning goals are necessary for intentional learning. To become successful intentional, effortful, learners, students must have an orientation to learning that goes beyond knowing facts, performing on tests, or completing assignments. They must understand learning as problem solving, have learning goals, and have metacognitive strategies. Of course, not all students develop learning goals on their own. In all cases, maybe particularly so when students believe intelligence is fixed, teachers must teach an appropriate stance about knowledge and model cognitive goals and planning. Some ways to do this are for teachers to think aloud and to teach metacognitive strategies in the contexts in which they are used. When students are entity theorists (intelligence is fixed), they need help focusing on their progress (Dweck & Legget, 1988). More focus on formative assessment and the use of activities that build on earlier successes might be useful.

In “How People Learn” we also read a series of articles that demonstrate metacognitive approaches to teaching and/or the mental processes used by experts in different disciplines. For example, in reading comprehension (Brown, 1980), history (Wineburg, 1991), physics (White & Frederiksen, 1988), and literacy (Palincsar & Klenk, 1992). After analyzing these articles, students understand that metacognitive skills are both self-regulatory skills used in planning and monitoring (developing goals and strategies, evaluating progress), and self-knowledge and improvement expertise (awareness of one’s knowledge and knowledge gaps, and awareness of when to use specific strategies and when to modify them).

By exploring these ideas, my students come to more reasoned understandings of the roles of students and teachers in learning. Students must be aware of their cognitive strategies. Teachers’ assignments must engage students in transforming ideas to create new knowledge, rather than in simply summarizing or learning facts. Learners’ roles must be expanded so they can practice strategies, get feedback on their process skills, and hopefully internalize them. Students should be engaged in consequential tasks that require the thinking strategies associated with expertise in the field and that help them make connections among ideas. Hopefully, my students will go on to teach in some setting where they will not repeat some of the school-based assignments that subvert the development of learning goals and of metacognitive strategies.

### Metacognition in the Geosciences

My work with Darby Dyar on visualizations in teaching mineralogy and geology is an opportunity to explore another set of disciplinary specific metacognitive strategies. Geology and mineralogy expertise includes thinking that is common to all scientists (e.g., how to reason from evidence). As in any field, there are specific learning goals, some of which may be difficult to master. Many of the learning challenges in the geosciences are of abstraction, which require both external and internal visualization (e.g. the ability to

coordinate a range of 3-D structural views to dynamic processes that occur in all planes). Thinking in these domains taxes one's ability to represent shapes and patterns over space and time, and not only requires memory of visual patterns and concepts, but also involves visual imagination. These are all capacities of our visual system, but in learning, the use and practice of these capacities must be applied to specific content. Spatial thinking in geosciences spans a huge range of scales, from the atomic (e.g., the crystalline structure of minerals) to the global (e.g., atmospheric circulation patterns). Some of the specific spatial reasoning tasks that geologists and mineralogists engage in include: a) recognizing, describing, and classifying the shape of an object, b) describing the position and orientation of objects, c) making and using maps, d) envisioning processes in three dimensions, and e) using spatial-thinking strategies to think about non-spatial phenomena (Kastens & Ishikawa, 2006). In addition, geoscientists must synthesize representations about 3D structures from memory and predict transformations in the physical world over long periods of time. Teaching in the geosciences must support student learning with regards to this complex, abstract thinking. The use of static visualizations in addition to text has been commonplace, and the addition of animated visualizations has been increasing with the development of new technologies.

### Visualization

The term *visualization* traditionally refers to activities of the visual imagination, but has been extended to refer to the creation and use of activities involving external images intended to bootstrap visual learning, which is how the term will be used here. Visualizations can be 2D or 3D, detailed or simple, true to actual form or highly abstracted, static or animated. In order to make use of them, learners must have a rudimentary knowledge of the concepts that the visualizations represent; they must understand how the components of the system are represented in the visual display, and they must understand how the display maps onto the real world. While apparent to the expert, these understandings about visualizations do not necessarily occur naturally for all learners. For this, and perhaps other reasons, the use of visualizations in teaching does not immediately improve learning for all students. There are some findings that point to the cognitive load involved in interpreting visual representations (Jones, Jordan, and Stillings, 2002) and to the difficulty of creating animated visualizations that remain true to all aspects of a complex system (Tversky, Morrison, & Betrancourt, 2002).

There are differences in learners in terms of their initial spatial abilities, further making sound tests of the use of visualizations difficult, but perhaps making a metacognitive approach to learning in a field requiring spatial visualization especially important. There are substantial research findings that males outperform females on spatial visualization tasks (Kimura, 1999; Voyer, Voyer, & Bryden, 1995; Linn & Petersen 1985). It is thought to be the greatest sex difference in cognitive function (Kimura 1999). Yet Newcombe et al. (2005) see these sex differences in the performance of spatial tasks only in children of middle and high socioeconomic status (SES), and not in children of low SES, suggesting it is sensitive to educational environment. A failure to teach the strategies used in spatial tasks could be contributing to sex differences in particular fields.

## Interactive Animation

The literature on the usefulness of visualizations in learning is complex and there are few claims that do not require qualification; studies often confound interactivity or the making of predictions with learning from an animation, both of which improve learning in and of themselves (Tversky et al., 2002). Animations cannot be looked at as a unitary teaching tool. The types of concepts and systems portrayed in each animation are further confounds (e.g. whether the concept includes change over time, spatial relations, interaction of moving parts, etc.). In some studies the animations conveyed more material than the conditions in which there were no animations. The ability to convey much information might be reason enough to use animations, and faculty might have preferences about their use that speak to the difficulties of talking about certain kinds of processes.

What does seem to be true, in general, is that a graphic is more useful in learning when it abstracts or points out the most salient qualities of the objects or situation represented. Animations can be used to highlight significant aspects of the visualization and show relationships between and among parts of a whole. Animations are most successful in supporting visual learning that requires re-orientation in space and for real-time changes. Re-orientation in space is a task necessary for understanding mineral structure.

Interactive animations allow the learner to stop and manipulate the animation so as to pose questions and test ideas, other strategies that for many students, must be taught. The use of animations is time consuming. This coupled with the additional work of making sense of animations might be why students do not universally like them (Tversky et al., 2002). Even if students don't choose to spend time making sense of animations of complex systems, it is entirely possible that the animations allow faculty to present ideas that are difficult to represent otherwise.

As textbooks more and more include costly interactive animations, we must not expect that they are necessarily used and understood outside of the classroom. It will take work to understand how they are used and whether they improve learning. As with other learning tools, a geoscience professor must be aware of learning requirements of interactive animations and teach the strategies for interpreting them, just as she or he must be aware of and point out the limitations of such displays (e.g. the limitation of computer screens for angles that are not 90 degrees, etc.). For many visual tasks, a 2-D representation is even more limited.

## What does this have to do with intentionality and effort?

As with any educational tool, there is a danger of the medium's becoming the message and of students' engaging with the surface features of an assignment. While students might look more engaged when working with an interactive animation, in order to put effort into the aspects of the task that will more likely result in learning, they must have learning goals for themselves, ask themselves questions about what they are seeing, understand what they will learn by engaging in the task, and understand where they might

be confused. Of course, that means they must work through the challenging thinking skills needed for success in the geosciences rather than simply care about getting the assignments done.

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## Metacognition During Discourse

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In my classroom, I often marvel at how much I learn while teaching, but I get frustrated when I realize my students are not having a similar experience. The reality is that I am not learning because I'm listening, I'm learning because I'm talking and explaining. I'm learning because I'm engaged in higher order thinking skills and processing information, and this is metacognition. Benjamin Bloom identified three types of learning: the cognitive (knowledge-based), affective (emotional), and the psychomotor (physical skills). Most academic teaching focuses on the cognitive domain, especially in the sciences, as this is the where most formative assessment occurs. Within the cognitive domain, more value is placed on higher order thinking skills (evaluation and synthesis), but the reality is that most teaching and evaluation occurs at the lower order (knowledge and comprehension). How do we get students to ascend this ladder of cognitive development without completely abandoning traditional teaching techniques and assessments? Cognitive learning is inextricably linked with the affective domain, and metacognition is the tool that transcends these domains. The goal, therefore, as an instructor, is to become effective in the affective, and to facilitate and model metacognition for students so that they may utilize this skill to attain higher order thinking skills.

Most academic instruction is done verbally, with a focus on teacher initiated lecture. However, going back to Socrates, it has been shown that students negotiate meaning and process information during discourse. In order to achieve cognitive conceptual change, student-student and teacher-student discussion is a necessary component to the classroom (Mercer, 2008). Weber, Maher, Powell, & Lee (2008) observe that when given a problem to discuss in a mathematics classroom, students often challenge the ideas and arguments of their peers in a way they may not do with an instructor. This discourse facilitates their own understanding of the concept and identifies misconceptions (Huang, Normandia, & Greer, 2005). Discussion between peers allows metacognition that develops critical thinking skills and allows students to deepen their own understanding (Shamir, Zion, & Spector Levi, 2008).

Traditionally, many conceptual models have been employed to aid in the understanding of science, but discourse needs to be implemented as a learning tool as well. Bricker and Bell (2008) state that the role of discussion in a science classroom is essential, because argumentation epitomizes the nature of science and is intimately linked with directed science outcomes. However, it is also essential for the understanding of course material. When I teach about the nature of science and argumentation in my classroom, I use a "gallery walk" to help with the concept. Students come up with a claim and post it for their peers to comment upon. They defend and modify their ideas during discussions with peers and come up with a new, arguably better, claim. The result of this experience not only deepens their understanding of the material, but it also illustrates what "peer reviewed" means and why this process is so important in science.



A modified Socratic Method has been employed successfully in classrooms to facilitate classroom discourse communities. Li-hsuan Yang (2007) published a study illustrating an environment where the instructor posed questions and students not only suggested potential answers, but they introduced other questions, potential sources of information, and refuted and supported each other's ideas. By setting the framework and driving the discussion, the instructor set her students up for success. She successfully modelled how the conversation would progress by asking levelled questions, but did not limit results by sticking to a script. Furtak and Ruiz-Primo (2008) suggest that by supplying formative prompts, an instructor can direct the students to think more explicitly, and in this way we can scaffold the discussion for students. By conducting a whole room question and answer session, Yang modified a potentially stressful single discussion into a whole group discourse. Students also use vernacular to explain their own understanding, which show synthesis, a higher level of thinking (Brown & Spang, 2008). In this modified Socratic environment, an instructor can validate student interpretations, which further contributes to confidence in the subject material. In my own classroom, students are much more likely to engage in a conversation when they are allowed to respond to the questions and answers of other students, as well as tailor the direction of the discourse. By creating a community of discourse, I can model metacognition by verbalizing my own thought processes through asking questions and seeking answers. I also help to restate student observations and questions, which facilitates academic language acquisition. These are just some ways in which discourse can be used to facilitate metacognition in the classroom, which will ultimately lead to better cognitive development.

I am interested in incorporating metacognition into my classroom in other ways, and this is why I am very excited to be attending this workshop. I look forward to meeting everyone in a few weeks!

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Learning About Thinking and Thinking About Learning:  
Metacognitive Knowledge and Skills for Intentional Learners  
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In an increasingly complex and interconnected world it is ever more important that students develop intellectual and practical skills for lifelong learning. Panel reports by the AAC&U (2002, 2007) call for "higher education to help college students become intentional learners who can adapt to new environments, integrate knowledge from different sources, and continue learning throughout their lives." Becoming an intentional learner includes "developing self-awareness about the reason for study, the learning process itself, and how education is used." Intentional, or "expert," learners are more purposeful, they are more aware of themselves as learners, and they "take the initiative to diagnose their learning needs, formulate learning goals, identify resources for learning, select an implement learning strategies, and evaluate learning outcomes" (Savin-Baden and Major 2004). Research on cognition and learning (e.g., see review in Bransford et al., 2000) indicates that expert learners are characterized by having better-developed metacognitive knowledge (about the learner, learning tasks, learning strategies, and content), metacognitive control (planning, monitoring, and self-evaluation), and reflection (a critical link between knowledge and control of the learning process) (Ertmer and Newby, 1996). If an important goal of higher education is to help students become intentional learners, then our curricula should reflect those aims. Most post-secondary instruction, however, remains focused on disciplinary content. Instruction about metacognitive knowledge and skills need not "displace" disciplinary content, but can instead be used to support ("wrap") learning of that content (Lovett, 2008).

The transition from being a dependent to independent learner involves major changes involving not only how students think, but also who they are. Fink's (2003) taxonomy of significant learning promotes lasting change in the learner through integration of foundational knowledge with learning how to learn and the affective domain (feelings, values, motivations, and attitudes of the learner). To help students develop into self-directing learners I include explicit instruction about learning in all of my courses. This "co-curriculum" on learning is interwoven with geoscience content in each course. The goals of the learning co-curriculum are: (1) to encourage students to be more intentional about their learning; (2) to help students develop their metacognitive knowledge and skills; and (3) to help students construct greater personal meaning with their new knowledge and understanding. This co-curriculum helps provide structure, or scaffolding, in a learning environment that may not always be familiar to all students. Together with Dexter Perkins, I developed a summary article entitled "Learning to Learn" (Wirth and Perkins, 2008) on the essential elements of learning. This document, which is the first reading assignment in all of my courses, explores various meanings of learning, understanding, and thinking. It also highlights research on the brain, learning styles, intellectual development, metacognition, collaborative learning, and the behavioral dimensions of grades. The learning document not only serves to help students develop their metacognitive knowledge and skills, it also helps establish that my expectations for student learning in the course go far beyond memorizing content.

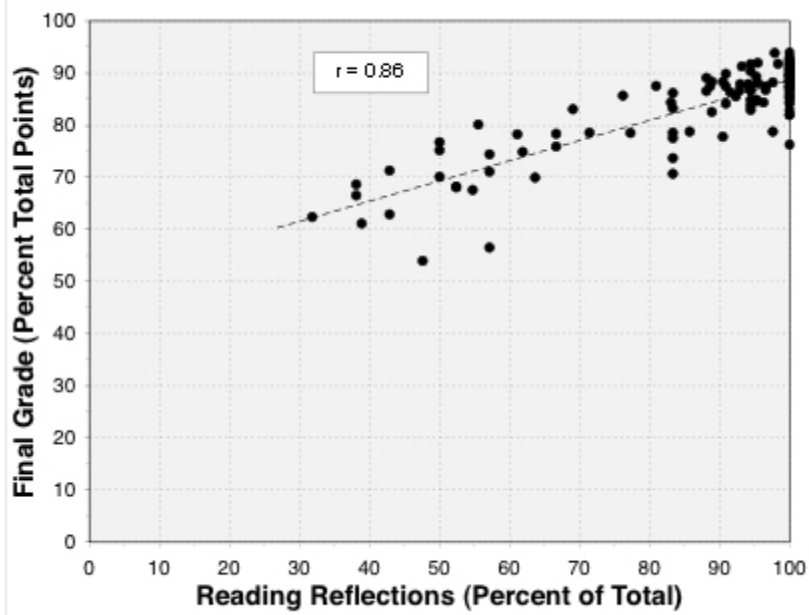


Figure 1. Plot of reading reflection scores versus final grades.

Wirth graph, metacognition essay Figure 1.

After introducing students to some of the elements of learning, I use a variety of activities to help them develop their metacognitive knowledge and skills. At the beginning of the semester students write a letter to the instructor, in the past tense and dated to the end of the semester, that describes what they did and how they changed to earn an "A" in the course. The purpose of this journal activity is to help students set goals and plan their learning. In other journal assignments, students reflect on the learning strategies they are employing, the success of these strategies, and modifications that they might undertake for improving their learning. Knowledge surveys, which have been described elsewhere (e.g., Nuhfer, 1996; Nuhfer and Knipp, 2003; on the SERC website), guide student learning, facilitate student mastery of course content and skills, and help students develop their monitoring and self-assessment skills. Reading reflections, which can be readily implemented in any class or discipline, are completed by students after each reading assignment and before coming to class (see example). These short reflections encourage students to deepen their understanding of the readings by summarizing the important concepts and by describing what was surprising or confusing to them. This activity not only promotes student reading before class and deepens their content knowledge, it also provides opportunities for students to develop their skills for monitoring and evaluating their learning. Although reading reflections constitute only a small fraction (5-10%) of total points in each course, student performance on these activities is a good predictor of their final course grade (Figure 1) suggesting that monitoring and evaluation skills are closely associated with deeper learning. An important goal is that these reflective activities will also help students develop as intentional learners.

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