Adolescents' Use of Self-Regulatory Processes and Their Relation to Qualitative Mental Model Shifts While Using Hypermedia

Jeffrey A. Greene, Roger Azevedo, University of Maryland, 3304 Benjamin Building, College Park, MD 20742
Email: jgreene@umd.edu, razevedo@umd.edu

Abstract: This study examined 148 adolescents' use of self-regulated learning (SRL) processes when learning about the circulatory system using hypermedia. All participants scored in the lowest category on a measure of conceptual understanding regarding their mental model. We examined participants' verbal protocols to determine the relationship between SRL processes and qualitative shifts in students' mental models from pretest to posttest. Results indicated that participants who exhibited a qualitative shift in their mental models, pretest to posttest, displayed differential use of six SRL processes. These SRL processes included metacognitive monitoring activities, learning strategies, and indications of task difficulty. We propose that these SRL processes can account for the participants' shift in mental model. Implications for the design of hypermedia learning environments are presented.

Complex science topics have many characteristics that make them difficult to understand (Azevedo, Winters, & Moos, 2004; Chi, 2005; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Hmelo-Silver & Azevedo, 2006; Jacobson & Kozma, 2000; Jacobson & Wilensky, 2006; Lajoie & Azevedo, in press). For example, in order to have a coherent understanding of the circulatory system, a learner must comprehend an intricate system of relations that exist at the molecular, cellular, organ, and system-levels (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Chi, de Leeu, Chiu, & LaVancher, 1994; Chi, Siler & Joeng, 2004). Understanding system complexity is sometimes difficult because the properties of the system are not available for direct inspection. In addition, students must integrate multiple representations (e.g., text, diagrams, animations) to attain a fundamental conceptual understanding and then use those representations to make inferences about how the system operates (Kozma, Chin, Russell, & Marx, 2000). These inferences and mental representations combine to form a learner's mental model of the system (see Chi, 2005; Jacobson & Archodidou, 2000; Markman & Gentner, 2000; Vosniadou & Brewer, 1992). Hypermedia learning environments can be used to address many of the difficulties above, including allowing for direct inspection of multiple representations and providing a non-linear, content-on-demand means of providing information (Jacobson & Kozma, 2000; Lajoie & Azevedo, in press). However, to gain the full benefits of using hypermedia learning environments to study complex and challenging science topics such as the circulatory system, students must regulate their learning (Azevedo, 2005; Azevedo & Cromley, 2004; Azevedo, Cromley & Siebert, 2004; Shapiro & Niederhauser, 2004). In this study, we focus on students' use of specific regulatory processes during learning with hypermedia and how those processes are related to qualitative shifts in students' mental models of the circulatory system.

Research on Self-Regulated Learning with Hypermedia

There are two issues regarding research on self-regulated learning of complex topics with hypermedia. First, most hypermedia learning studies continue to focus only on students' declarative knowledge of basic topics (e.g., McManus, 2000). We argue this approach is inadequate when examining students' learning of complex and challenging science topics. We believe measures of mental models are necessary to accurately assess student learning of such complex topics. The second issue is how to determine what aspects of SRL are most helpful in promoting the mental model shifts necessary to truly understand complex content.

Little research has been conducted that examines what kinds of SRL processes—cognitive, motivational/affective, behavioral, and contextual— are most helpful during the cyclical and iterative phases of planning, monitoring, control, and reflection that take should place when students learn with hypermedia environments (e.g., Azevedo, Guthrie, & Seibert, 2004, Azevedo, Cromley, Winters, Moos, & Greene, 2005). For example, previous research indicates that the use of feeling of knowing (FOK) as a metacognitive monitoring activity is related to enhanced understanding of the circulatory system (e.g., Azevedo & Cromley, 2004). By contrast, students' excessive use of control of context as a metacognitive monitoring activity has been associated with less frequent shifts in students' mental models because it indicates too much monitoring of the hypermedia learning environment rather than focusing on learning (Azevedo et al., 2006). More research such as this is needed to determine what other kinds of SRL processes are associated with learning in hypermedia environments. This research must focus on both assessments of conceptual understanding, such as mental model measures, and the SRL processes utilized by successful learners.

In other words, we believe qualitative shifts in conceptual understanding, as measured by movement from a less sophisticated mental model at pretest to a more sophisticated mental model at posttest during learning with hypermedia, are associated with the use of specific SRL variables and their frequency during learning. In this study, we converged both product and process data to test this theory by examining the frequency of use of these SRL variables in relation to qualitative shift in students' mental models. We believe determining which SRL processes are associated with mental model shifts is an important contribution toward both helping students more effectively utilize hypermedia environments and informing the design of those environments as well (Azevedo et al., 2005, 2006; Brusilovsky, 2004; Jacobson, in press; Lajoie & Azevedo, in press).

Method

Participants

Participants were 148 middle school and high school students (MS *N*=82; HS *N*=66) from two schools located outside a large mid-Atlantic city. The mean age of the middle school students was 12.2 years (*SD* = .59) and the mean age of the high school students was 14.9 years (*SD* = .97). The students were tested before they had covered the content of the hypermedia learning environment in their class. Only students that were scored as having a "low" mental model of the circulatory system on the pretest (see below) were included in this study.

Measure

The paper-and-pencil materials consisted of a consent form, a participant questionnaire, a pretest, and a posttest. All of the paper-and-pencil materials were constructed in consultation with both a science teacher and a faculty member at a school of nursing and used in several studies conducted by Azevedo and colleagues (e.g., Azevedo et al., 2005). The questionnaire asked participants to list their age, class from which they were recruited, and any science or health courses they had taken in the last year.

Both the pretest and the posttest consisted of a sheet that contained the instruction, *"Please write down everything you can about the circulatory system. Be sure to include all the parts and their purpose, explain how they work both individually and together, and also explain how they contribute to the healthy functioning of the body"*. The posttest was identical to the pretest. Both the pretest and posttest we designed to be open-ended in order to prompt the participant to generate the declarative, procedural, and inferential knowledge underlying his or her mental model.

Hypermedia Learning Environment (HLE)

During the experimental phase, the participants used an HLE called Microsoft Encarta DVD (2003) to learn about the circulatory system. In this HLE, the circulatory system is covered in three articles, comprised of 16,900 words, 18 sections, 107 hyperlinks, and 35 illustrations. These three main articles covered the blood, circulatory system, and heart. The HLE included a table of contents for each article and both global and local search functions (e.g., "find" in article and "find" between articles). Participants were told that they could choose to access any article within Encarta to meet their learning goals, but that these three articles were likely to be the most relevant.

Procedure

The authors, along with three trained graduate students, individually tested all the participants. Informed consent was obtained from all participants' parents. First, the participant questionnaire was handed out, and participants were given as much time as they wanted to complete it. Second, the pretest was handed out, and participants were given 20 minutes to complete it. Participants wrote their answers on the pretest and did not have access to any instructional materials. Third, the experimenter provided instructions for the learning task. The following instructions were read and presented to the participants in writing.

"*You are being presented with a hypermedia learning environment, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students use hypermedia environments to learn about the circulatory system. Your task is to learn all you can about the circulatory system in 40 minutes. Make sure you learn about the different parts and their purpose, how they work both individually and together, and how they support the human body. We ask you to 'think aloud' continuously while you use the hypermedia environment to learn about the circulatory system. I'll be here in case anything goes wrong with the computer or the equipment. Please remember that it is very important to say everything that you are thinking while you are working on this task."*

Participants then began the learning session, and an experimenter remained nearby to remind them to keep verbalizing when they were silent for more than three seconds (e.g., *"Say what you are thinking"*). All participants were given a 40-minute learning time to use the hypermedia environment, and they had access to the instructions during the learning session. Participants were allowed to takes notes and draw during the learning session, although not all chose to do so. After the learning session, all participants were given 20 minutes to complete the posttest without their notes or any other instructional materials.

Coding and Scoring

The values for each participant's pretest and posttest mental model were recorded and used in a subsequent analysis to determine the shift in their conceptual understanding (see inter-rater agreement below). Given that we were most interested in how participants learned during the task, as opposed to how much prior knowledge they may or may not have had, we only included participants in this study who scored in the "low" category at pretest. For analysis purposes, each participant was therefore classified only by her or his posttest score: low, intermediate, or high.

Mental models

To code posttest mental models, we utilized Azevedo and colleagues' method (Azevedo & Cromley, 2004; Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004; Azevedo et al., 2005) of determining the participants' mental models, which is an elaboration of Chi and colleagues' research (Chi et al., 1994, 2000, 2005). Using 3 mental model categories which represent the progression from a low level of understanding to a high level of understanding, we characterized each participant's essay. The model categories were designed to represent qualitative differences in participants' understanding of the circulatory system. A participant was placed in the "low" mental model category if his or her essay did not indicate an understanding above a single-loop path of the circulatory system, or if it did not mention the lungs. A participant with an "intermediate" understanding of the circulatory system, on the other hand, wrote an essay showing that he or she understood that the circulatory system was a single loop with lungs. Finally, a participant placed in the "high" mental model category displayed an understanding of the double-loop concept of the circulatory system. For a complete description of the mental models and their scoring, see Azevedo and colleagues (2005).

Students' verbalizations

The raw data collected from this study consisted of 5,920 minutes (98.67 hours) of audio and video tape recordings from 148 participants, who gave extensive verbalizations while they learned about the circulatory system. During the first phase of data analysis, a graduate student transcribed the audio tapes and created a text file for each participant.

Participants' regulatory behavior

Azevedo and colleagues' (Azevedo et al, 2005, 2006; Azevedo & Cromley, 2004; Azevedo, Cromley & Siebert, 2004; Azevedo, Guthrie, & Seibert, 2004) model of SRL was used to analyze the participants' regulatory behavior. Their model is based on several recent models of SRL (Corno & Mandinach, 1983; Pintrich, 2000; Schunk, 2005; Winne, 2001; Winne & Hadwin, 1998; Zimmerman, 2000, 2001). Their model builds upon Winne's (2001) and Pintrich's (2000) formulation of self-regulation as a four-phase process by highlighting processes essential to the effective use of hypermedia learning environments. Specifically, students who effectively utilize HLEs engage in most if not all of the following: planning and goal-setting; activation of prior knowledge; monitoring aspects of the task, their performance, and the context; engaging in the active and intentional control of these regulatory processes; and reflecting upon the outcomes of these processes. An example of an HLE-specific SRL variable would be coordinating information sources (COIS), where students compare what they are reading in text to a diagram displayed on the screen.

The classes, descriptions and examples from the think-aloud protocols of the planning, monitoring, strategy use, task difficulty and demands, and interest variables used for coding the participants' regulatory behavior are found in the Appendix. We used Azevedo and colleagues' SRL model to re-segment the data from the previous data analysis phase. This phase of the data analysis yielded 17,789.6 segments (M = 120.2 per participant) with corresponding SRL variables. A trained graduate student used the coding scheme and coded all of the transcriptions by assigning each coded segment with one of the 35 SRL variables.

Inter-rater agreement

Inter-rater agreement was established by having the graduate students with external training use the description of the mental models developed by Azevedo and colleagues (Azevedo & Cromley, 2004; Azevedo, Cromley & Siebert, 2004; Azevedo, Guthrie, & Seibert, 2004; Azevedo et al., 2005,.2006). They independently coded all selected protocols (pre- and posttest essays of the circulatory system from each participant). There was agreement on 287 out of a total of 296 participant descriptions, yielding an inter-rater agreement of .97. Inter-rater agreement was also established for the coding of the participants' behavior by comparing the individual coding of the graduate students with that of the second author. The second author independently re-coded all 17,789.6 protocol segments (100%). There was agreement on 17,256 out of 17,789.6 segments yielding an inter-rater agreement of .97. Inconsistencies were resolved through discussion among the co-authors and graduate students.

Results

Of the 148 participants with low mental model pretest scores, 92 (62%) had a low, 23 (16%) had an intermediate, and 33 (22%) had a high posttest mental model score. Several two-way contingency table analyses were produced to determine whether the distribution of participants' use of various SRL processes above or below the median (for a complete description of the coding and analysis plan, see Azevedo & Cromley, 2004, p. 528) differed across posttest mental model categories (low, intermediate, high). A series of chi-square analyses were performed for each SRL variable, with the subject-grouping variable being their posttest mental model score (low, intermediate, high). Of the 35 SRL variables examined, 6 were significantly related to posttest mental model category: Change of Context (COC), Coordinating Informational Sources (CoIS), Expectation of Adequacy of Information (EA) Feeling of Knowing (FOK), Inference (INF), and Knowledge Elaboration (KE).

Control of Context

Control of context occurred any time a participant chose to click on a hyperlink or otherwise leave their current representation for a new one. Participants exert control over the context for a number of reasons. However, over the course of a 40-minute learning task, frequent control of context, here interpreted as changing between representations, can be indicative of a lack of goal directed behavior.

COC and posttest mental model score were found to be significantly related, Pearson χ^2 (2, N = 148) = 8.554, p = .014, Cramér's V = .240. Frequencies by mental model posttest score are shown below (see Table 1). These data suggest that more frequent use of COC is associated with students who did not make a shift from their low mental model at pretest to a more advance mental model at posttest (intermediate or high).

Table 1: SRL Processes Use Above and Below the Median, by Posttest Mental Model Score Group

		Posttest Mental Model Score Group		
SRL Process		Low	Intermediate	High
Control of Context (COC)				
	Above Median	54	8	11
	Below Median	38	15	22
Coordinating Informational Sources (COIS)				
	Above Median	38	14	22
	Below Median	54	9	11
Expecting the Adequacy of Information (EAI)				
	Above Median	43	17	14
	Below Median	49	6	19
Feeling of Knowing (FOK)				
	Above Median	34	13	27
	Below Median	58	10	6
Inferences (INF)				
	Above Median	36	14	23
	Below Median	56	9	10
Knowledge Elaboration (KE)				
	Above Median	20	10	15
	Below Median	72	13	18

Coordinating Informational Sources

Participants exhibited the coordination of informational sources when they explicitly stated that they were comparing two kinds of representations. For example, this process most often occurred when a participant would compare what he or she read in the text with a picture of the heart. An example of this is:

"I am just putting [what participant just read] together with the picture..um..okay"

COIS and posttest mental model score were found to be significantly related, Pearson χ^2 (2, N = 148) = 7.536, p = .023, Cramér's V = .226. Frequencies by mental model posttest score are shown below (see Table 1). Participants in the intermediate and high mental model posttest score groups were far more likely to utilize COIS above the median than participants in the low category. This suggests that COIS is associated with positive learning during the task.

Expectation of Adequacy of Information

EAI is a strategy where students monitor their current level of understanding and use that information to determine whether a particular portion of the HLE will be helpful to them or not. An example of this is:

> "I may want to go back to the picture, just to, I don't know where [the different parts of the heart] are, really."

EAI and posttest mental model score were found to be significantly related, Pearson χ^2 (2, N = 148) = 6.410, p = .041, Cramér's V = .208. Frequencies by mental model posttest score are shown below (see Table 1). Participants in the intermediate and high mental model posttest score groups were more likely to utilize EAI above the median than participants in the low category.

Feeling of Knowing

FOK is a metacognitive monitoring activity that involves the learner realizing that they are familiar with a concept but not being able to recall it completely. An example of a participant FOK is when they read text and struggle to synthesize its content:

> "The capillaries are the smallest veins that branch off from the big artery thing…wait, they are like a branch between the vein and artery, actually."

FOK and mental model shift group were found to be significantly related, Pearson χ^2 (2, N = 148) = 20.016, p = .000, Cramér's V = .368. Frequencies by mental model posttest score group are shown below (see Table 1). These data suggest that use of FOK above the median is associated with students making a qualitative shift to a higher mental model category at posttest. Participants in the intermediate and high categories were much more likely to use FOK above the median.

Inference

Inference (INF) is a learning strategy that involves participants encountering content in the HLE and drawing a conclusion from that content. An example of inference is:

> "If you add iron to your diet it can help cure iron-deficiency amenia [sic]."

INF and mental model posttest score category were found to be significantly related, Pearson χ^2 (2, N = 148) = 10.531, p = .005, Cramér's V = .267. Frequencies by mental model posttest score group are shown below (see Table 1). These data suggest that participants who experience a shift in mental model are also more likely to be above the median in their use of inference.

Knowledge Elaboration

Knowledge Elaboration (KE) is a learning strategy that involves the participant expanding on material within the HLE, including analogical thinking. An example of this is when a participant utilizes an analogy to better understand the content:

> "And in the diagram I see the lumen is, like, the center part – like wood"

KE and mental model shift group were found to be significantly related, Pearson χ^2 (2, N = 148) = 8.655, p = .013, Cramér's V = .242. Frequencies by mental model posttest score group are shown below (see Table 1). These data are interesting in that the low posttest mental model group had a larger number of total participants above the median across all three groups, but within the low category most students scored below the median. The results also indicate that the two shift groups that experienced qualitative change in mental model pre to posttest (intermediate and high) had a much more even split between above and below median participants. This suggests that while less than 50% of all participants engaged in KE above the median, the posttest score groups experiencing qualitative change had proportionally more of their participants above the median. This occurred because many students did not invoke KE at all, leading to the median being 0.

Summary of Results

There data provide a unique perspective upon how participants use HLEs to learn about complex and challenging science topics. Overall, these data make the case that participants in middle and high school who experience a positive qualitative shift in their mental models are also more likely to be above the median in strategy use and monitoring their understanding, through the use of SRL processes such as INF and FOK. Thus, hypermedia environments that promote these SRL behaviors would seem to be more likely to elicit qualitative mental model shift. Excessive controlling of the context, on the other hand, would seem to be an indicator of a lack of goal directed behavior on the part of the participant, and might be a cue that the participant should reassess his or her learning goals.

Conclusions

Hypermedia learning environments hold the potential to assist participants in their learning of complex science topics. However, the very non-linear, dynamic, and user-controlled aspects of HLEs that make them so powerful also make them sometimes difficult to navigate. We argue that successful learners with HLEs are those that are able to self-regulate. These participants make plans, monitor their progress, control their learning and environment to maximize their progress, and reflect upon what they have done. Our findings support our views, in that participants who experience a positive qualitative shift in their mental model of the circulatory system are more likely to utilize certain SRL processes more often than their less successful peers. Clearly, SRL processes aimed at conceptual understanding (COIS, EA, FOK, INF, KE) are associated with learning, whereas excessive COC seems to be an indicator of potential trouble with planning. Therefore, this suggests that the increased complexity of HLEs best serves those learners that are able to quickly acclimate to the environment and begin to direct their cognitive energies toward learning strategies, rather than spending time learning about the actual mechanics of the environment. The practical applications of this research lie in the design of HLEs that both decrease the need for lower-level SRL behaviors such as change of context and increase the use of higher-order ones such as FOK. More research remains to be done, however, on how these higher-order SRL behaviors can be prompted and taught during student use of HLEs. The findings suggest certain SRL processes to be taught, but more work is required regarding how effective HLEs can be in training students to use higher-order learning strategies. Future research should focus on the best means of inculcating effective SRL behaviors through on-line methods, so that HLEs can teach both content and the actual process of learning.

References

Azevedo, R. (2005). Computer environments as metacognitive tools for enhancing learning. *Educational Psychologist, 40,* 193-197.

Azevedo, R., & Cromley, J.G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology, 96*(3), 523-535.

Azevedo, R., Cromley, J.G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*, 344-370.

Azevedo, R., Cromley, J.G., Winters. F.I., Moos, D.C., & Greene, J.A. (2006). Using computers as metacognitive tools to foster students' self-regulated learning. *Technology, Instruction, Cognition, and Learning Journal, 3,* 97-104.

Azevedo, R., Cromley, J.G., Winters, F.I., Moos, D.C., & Greene, J.A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science, 33,* 381-412.

Azevedo, R., Guthrie, J.T., & Seibert, D. (2004). The role of self-regulated learning in fostering students' conceptual understanding of complex systems with hypermedia. *Journal of Educational Computing Research, 30*(1), 87-111.

Azevedo, R., Moos, D.C., Winters, F.W., Greene, J.A., Cromley, J.G., Olson, E.D., & Godbole-Chaudhuri, P. (2005b). Why is externally-regulated learning more effective than self- regulated learning with hypermedia? In C-K. Looi, G. McCalla, B. Bredeweg, & J. Breuker (Eds.), *Artificial intelligence in education: Supporting learning through intelligent and socially informed technology* (pp. 41-48). Amsterdam , The Netherlands : IOS Press.

Azevedo, R., Winters, F.I., & Moos, D.C. (2004). Can students collaboratively use hypermedia to learn about science? The dynamics of self- and other-regulatory processes in an ecology classroom. *Journal of Educational Computing Research, 31,* 215-245.

Brusilovsky, P. (2004). Adaptive navigation support in educational hypermedia: The role of student knowledge level and the case for meta-adaptation. *British Journal of Educational Technology, 34*(4), 487-497.

Chi, M.T.H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*, 161-199.

Chi, M.T.H. (2000). Self-explaining: The dual processes of generating inference and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology: Educational design and cognitive science* (Vo. 5, pp. 161 – 238). Mahwah, NJ: Erlbaum.

Chi, M.T.H., de Leeuw, N., Chiu, M.-H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439-477.

Chi, M. T.H., Siler, S., & Jeong, H. (2004). Can tutors monitor students' understanding accurately? *Cognition and Instruction, 22*, 363-387.

Chi, M. T.H., Siler, S., Jeong, H., Yamauchi, T., & Hausmann, R. (2001). Learning from human tutoring. *Cognitive Science, 25*, 471-534.

Corno, L., & Mandinach, E. (1983). The role of cognitive engagement in classroom learning and motivation. *Educational Psychologist, 18*(2), 88-109.
Hmelo-Silver, C., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *Journal of the Learning Sciences.15,* 53-61.
Jacobson, M. J. (in press). From non-adaptive to adaptive educational hypermedia: Theory, research, and design issues. *Advances in Web-based education: Personalized learning environments.*
Jacobson, M., & Archodidou, A. (2000). The design of hypermedia tools for learning: Fostering conceptual change and transfer of complex scientific knowledge. *Journal of the Learning Sciences, 9*(2), 149-199.
Jacobson, M., & Kozma, R. (2000). *Innovations in science and mathematics education: Adavnced designs for technologies of learning*. Mawah, NJ: Erlbaum.
Jacobson, M., & Wilensky, U. (2006). C*omplex systems in education: Scientific and educational importance and research challenges for the learning sciences. Journal of the Learning Sciences, 15,* 11-34.
Kozma, R., Chin, E., Russell, J., & Marx, N. (2000). The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. *Journal of the Learning Sciences,* 9(2), 105-144.
Lajoie, S.P., & Azevedo, R. (in press). Teaching and learning in technology-rich environments. In P. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (2nd ed.). Mahwah, NJ: Erlbaum.
Markman, A., & Gentner, D. (2001). Thinking. *Annual Review of Psychology, 52*, 223-248.
McManus, T. (2000). Individualizing instruction in a Web-based hypermedia learning environment: Nonlinearity, advance organizers, and self-regulated learners. *Journal of Interactive Learning Research, 11*, 219-251.
Pintrich, P.R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.
Schunk, D. (2005). Self-regulated learning: The educational legacy of Paul R. Pintrich. *Educational Psychologist,* 40, 85-94.
Shapiro, A., & Niederhauser, D. (2004). Learning from hypertext: Research issues and findings. In D. H. Jonassen (Ed.). *Handbook of Research for Education Communications and Technology (2nd ed).* Mahwah, NJ: Erlbaum.
Vosniadou, S., & Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535-85.
Winne, P.H. (2001). Self-regulated learning viewed from models of information processing. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 153-189). Mawah, NJ: Erlbaum.
Winne, P.H., & Hadwin, A.F. (1998). Studying as self-regulated learning. In D.J. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Metacognition in educational theory and practice* (pp. 277-304). Hillsdale, NJ: Erlbaum.
Zimmerman, B. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (2nd ed.)(pp. 1-37). Mahwah, NJ: Erlbaum.
Zimmerman, B. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). San Diego, CA: Academic Press.

Acknowledgements

This research was supported by funding from the National Science Foundation (REC#0133346) awarded to the second author. The authors thank Jennifer Cromley, Fielding Winters, and Dan Moos for their help with data collection.