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Self-efficacy and prior domain knowledge: to what extent does monitoring mediate their relationship with hypermedia learning?

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Abstract While research has documented the key role of monitoring processes during hypermedia learning, limited empirical research has used process data to examine the possibility that these processes mediate the relationship between motivational constructs (such as self-efficacy) and cognitive factors (such as prior domain knowledge) with hypermedia learning outcomes. This multi-method study addressed this issue by examining: (1) The extent to which the relationship between self-efficacy and hypermedia learning outcomes is mediated by the use of specific monitoring processes and; (2) The extent to which the relationship between prior domain knowledge and hypermedia learning outcomes is mediated by the use of specific monitoring processes. Participants included 68 education majors. A self-report questionnaire was used to measure self-efficacy, a pretest was used to measure prior domain knowledge, a posttest was used to measure learning outcomes, and a think-aloud protocol were used to identify the deployment of monitoring processes during a 30-min hypermedia learning task. Results indicated that the relationship between self-efficacy and specific monitoring processes (*Monitoring Understanding*, *Monitoring Environment*, and *Monitoring Progress Towards Goals*) was significantly detectable. Additionally, the relationship between prior domain knowledge and *Monitoring Understanding* was significantly detectable. Lastly, regression analyses revealed that the relationship between self-efficacy and hypermedia learning outcomes was mediated by the extent to which participants monitored their understanding and the environment.

Keywords Metacognition · Self-regulated learning · Hypermedia · Self-efficacy · Motivation · Cognitive processes · Science · Mental models · Mixed methodology

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Various types of computer-based learning environments (CBLEs) have been used to facilitate student learning (Azevedo 2008; Jacobson 2008; Lajoie & Azevedo 2006; Scheiter & Gerjets 2007). For example, hypermedia allows the learner to control the sequencing of information and provides the learner with multiple representations presented in a non-linear fashion (Jacobson 2008). This specific type of CBLE often integrates text with various types of static and dynamic representations of information, including digital audio and video, animations, and access to other types of informational resources (Azevedo & Jacobson 2008; Jacobson & Azevedo 2008). Furthermore, these multiple representations are hyperlinked, and thus the design and structure of hypermedia requires a learner to deploy key cognitive and metacognitive while making decisions regarding which representations to access during learning (Azevedo 2007, 2008; Greene & Azevedo 2007; Jacobson 2008; Moos & Azevedo 2006, 2008a, b; Niederhauser 2008; Shapiro 2008). These cognitive and metacognitive processes are collectively categorized as *self-regulated learning* processes (see Azevedo 2007, 2008; Azevedo & Witherspoon 2009; Azevedo et al. 2007; Greene et al. 2008; Moos & Azevedo 2006; 2008a, b). An emerging body of empirical research has provided rich and informative data on the relationship between specific self-regulated learning (SRL) processes and learning outcomes with hypermedia. However, the possibility that SRL processes act as mediator variables with various constructs and learning outcomes with hypermedia has received much less attention, particularly from research that has utilized process data from think-aloud protocols. This study attempts to further the field by using a think-aloud protocol to examine the extent to which specific SRL processes related to metacognition act as mediator variables with self-efficacy, prior domain knowledge, and learning outcomes with hypermedia. The following sections first highlight previous research that has examined the role of SRL processes in learning outcomes with hypermedia, and then presents literature which explains why SRL processes related to metacognition may act as mediator variables with self-effficacy and prior domain knowledge.

Self-regulated learning with hypermedia

In order to properly present how researchers have examined self-regulated learning (SRL) with hypermedia, it is important to briefly identify the critical assumptions of this theoretical perspective. The field of SRL research consists of many camps and perspectives that sometimes focus on different constructs (Azevedo 2009; Boekaerts et al. 2000; Schunk & Zimmerman 2008; Zimmerman & Schunk 2001). However, these perspectives share four common assumptions that provide the foundations for all SRL models (Pintrich 2000). First, an underlying construct of most SRL models is that students are proactive in a constructive process of learning. Students are assumed to actively construct their own strategies, goals, and meaning from information available in their own minds as well as from the external world. Second, most SRL models assume that students can potentially regulate and monitor certain aspects of their cognition, behavior, and motivation. Due to individual differences and developmental constraints, learners do not constantly monitor and control their cognition, behavior, and adoption of goals in all contexts. Third, most models assume that all human cognitive behavior is goal-directed and that self-regulated learners modify their behavior to achieve a desired goal. Individuals set goals for their learning, monitor their progress towards these goals, and then adapt and regulate their behavior, cognition, and motivation to reach those goals. Fourth, most models assume that self-regulatory behavior is a mediator between an individual's performance, contextual factors, and personal characteristics.

Recent research has used a SRL model that combines key components of Pintrich's (2000) formulation of self-regulation as a four-phase process and draws from Winne (2001) and Winne and Hadwin (1998, 2008) information processing theory (IPT) of SRL (see Azevedo et al. 2006). This line of research has focused on SRL processes related to *cognition* and *metacognition*. For example, Azevedo et al. (2005) used think-aloud data to measure participants' use of specific SRL processes during learning. Findings indicated that there were differences in how participants self-regulated their learning, particularly with respect to cognitive and metacognitive processes. While some participants self-regulated their learning by activating prior knowledge and monitoring their cognitive activities, other participants self-regulated their learning by using strategies such as re-reading, taking notes, and summarizing. This line of research has provided critical evidence on the role of SRL processes in learning outcomes with hypermedia. This line of research has indicated that monitoring, an important aspect of metacognition, assumes a particularly critical role when learners are engaged with a nonlinear environment such as hypermedia. It should be noted that hypermedia environments are not uniquely nonlinear. Learners can engage the learning process in a nonlinear fashion with any medium that allows them to access information in a non-contiguous manner. This current study examined a hypermedia learning environment because it has been increasing in prevalence within educational settings and current research has focused on challenges learners face with this environment.

Metacognition and learning with hypermedia

Metacognition refers to the knowledge of one's thinking and the ability to reflect and modify processes and strategies related to this knowledge (Flavell 1979, 1985; Schraw & Dennison 1994). It has been demonstrated that metacognition significantly affects learning in most environments (Azevedo & Witherspoon 2009; Bendixen & Hartley 2003; Schraw 2007; Veenman 2007), and is particularly important during learning with nonlinear environments, such as hypermedia (Greene & Azevedo 2009; Scott & Schwartz 2007). Scott and Schwartz (2007) identify a number of potential factors related to metacognition that may impede learning with hypermedia, including the need for learners to integrate and comprehend the information in the environment while simultaneously monitoring the structure of the environment. In order to achieve this balance of content comprehension and effective navigation within hypermedia, learners must deploy several monitoring processes, an important aspect of metacognition. In particular, students need to *monitor*: (1) Their emerging understanding (i.e. judgment of learning [JOL[1]]; Azevedo et al. 2004a; Azevedo et al. 2005; and feeling of knowing [FOK[1]]; Moos & Azevedo 2006, 2008a,b); (2) the relevancy of the information in the environment (i.e. content evaluation; Azevedo et al. 2004b); and (3) their progress towards the learning goal (Azevedo et al. 2005, Azevedo & Witherspoon 2009). Use of these monitoring processes better enables learners to manage the high degree of control when learning with hypermedia (Greene & Azevedo 2007; Schwartz et al. 2004). However, as noted earlier, the bulk of this research has examined the

[1] Our operational definitions of FOK and JOL represent adaptations of the way these terms have been used to examine metacognitive judgments in laboratory tasks (see Metcalfe & Dunlosky 2008 for a recent review).

direct effect of monitoring processes on learning outcomes. A promising direction for future research is to consider the possibility that specific monitoring processes may act as mediator variables, particularly for processes related to the initiation of behavior.

Motivational variables are a natural consideration for this direction of research as motivation is broadly defined as perceptions of a situation that affect the direction, vigor, and choice of behavior (Eccles et al. 2006; Moos & Azevedo 2009; Schunk 2008; Schunk & Zimmerman 2008; Wigfield & Eccles 2002; Winne & Hadwin 2008; Zimmerman 2008). The field of motivation includes a vast array of constructs (see Murphy & Alexander 2000 for an overview of motivation terminology). Research examining learning with hypermedia suggests that the motivation construct of *self-efficacy* is of particular interest. Studies have suggested that individual differences in self-efficacy, defined as self-perception of one's capabilities to meet situational demands based on current states of motivation, courses of actions needed, and cognitive resources (Bandura 1997; Wood & Bandura 1989), may explain individual differences in learning processes with hypermedia. For example, MacGregor (1999) videotaped 7th and 11th graders while they used a commercially produced instructional hypermedia system to learn about twelve biodomes (e.g., desert, temperate deciduous forest, tundra). The focus of this study was to investigate the relation between self-efficacy and navigation in a hypermedia learning environment. Participants' navigation was grouped into three categories: Concept Connector, Sequential Studier, or Video Viewer. The participants were characterized as being concept connectors if they demonstrated need for further examples by cross-linking to other related nodes of information. Sequential studiers were described as students who accessed objects on the screen in a linear order, typically from left to right or top to bottom. Lastly, participants who were typified as being video viewers demonstrated a primary interest in videos. Results indicated that participants with higher levels of self-efficacy tended to structure their navigation in more purposeful manners; that is, these participants tended to be characterized as concept connectors because they made non-sequential connections of nodes. On the other hand, participants with lower self-efficacy tended to be characterized as sequential studiers due to their linear navigation of the hypermedia environment. This line of research suggests that self-efficacy is related to monitoring the relevance of content, which is an important aspect of navigation within a hypermedia environment. This line of research, coupled with previous research highlighting the direct effect of monitoring processes on learning with hypermedia (e.g., Azevedo et al. 2005, 2007, 2008; Moos & Azevedo 2008a, b), suggests that the relationship between self-efficacy and learning with hypermedia is mediated by specific monitoring processes.

A second variable that should be examined when considering the possibility that monitoring processes may act as a mediator variable is *prior domain knowledge*. Research using on-line methods has suggested a relationship between prior domain knowledge and use of monitoring processes during learning. Some learners demonstrate an inability to accurately monitor their learning (Dunlosky et al. 2005), which may be due to limited prior domain knowledge (Chen & Ford 1998; Last et al. 2001; Nielson 2000). Chen et al. (2006) suggested that monitoring the relevancy of information within hypermedia is, in part, dependent on an understanding of the conceptual structure of the domain. Thus, learners who have limited understanding of the conceptual structure of the domain have little to guide their interaction with hypermedia, which explains why learners with lower prior domain knowledge have more difficulty navigating in this environment (Shapiro 2004). Similarly, Moos and Azevedo (2008a) found that learners with higher prior domain knowledge tended to use more monitoring processes than learners with lower prior domain knowledge.

Current study

The preceding sections suggest that while previous research has empirically examined monitoring processes related to SRL, there are some current issues that should be considered in future research. This current study addressed these issues by examining the following concerns. First, as highlighted by Bendixen and Hartley (2003), there is currently limited research on the role of monitoring during learning with hypermedia. This current study capitalizes on Azevedo and colleagues line of research and use of process data (i.e. think-aloud protocols; Ericsson 2006; Ericsson & Simon 1994) to further examine the role of monitoring processes in learning outcomes with hypermedia. Specifically, this current study attempts to further the field by examining the possibility that specific monitoring processes act as mediating varibales in the relationship between *prior domain knowledge* and *self-efficacy* with hypermedia learning outcomes. The following three research questions and hypotheses guided this study:

1. To what extent is self-efficacy and prior domain knowledge related to the use of specific monitoring processes during learning with hypermedia? It was hypothesized that a positive relationship between self-efficacy, prior domain knowledge, and the frequency in which participants use “Monitoring Understanding” and “Monitoring Environment” processes would be statistically detectable. This hypothesis is derived from previous research which has suggested that prior domain knowledge is positively related to the extent to which learners use monitoring processes while learning with hypermedia (i.e. Moos & Azevedo 2008a) and research suggesting that self-efficacy is a strong predictor of how learners interact with a hypermedia environment (i.e. MacGregor 1999).
2. To what extent is the relationship between self-efficacy and learning outcomes mediated by the use of specific monitoring processes? It was hypothesized that the relationship between self-efficacy and learning outcomes with hypermedia would be mediated by participants' use of “Monitoring Understanding” and “Monitoring Environment” processes, and this relationship would be significantly detectable. This hypothesis was derived from previous research using think-aloud protocols to examine learning outcomes with hypermedia (e.g., Azevedo et al. 2005, 2007, 2008; Moos & Azevedo 2008a, b) which has routinely found a positive relationship between processes related to participants' monitoring of their understanding and monitoring the content within the hypermedia environment.
3. To what extent is the relationship between prior domain knowledge and learning outcomes mediated by the use of specific monitoring processes? As with the hypothesis for research question two, it was hypothesized that the relationship between prior domain knowledge and learning outcomes with hypermedia would be mediated by participants' use of “Monitoring Understanding” and “Monitoring Environment” processes, and this relationship would be significantly detectable.

Method

Participants

Sixty-eight (N=68) undergraduate students participated in this study. This sample consisted of three freshman (4%), 11 sophomores (16%), 23 juniors (34%), and 28 seniors (41%).

Three participants did not report their class standing (5%). Fourty-nine were females (72%). This gender distribution is typical of undergraduate education majors. The participants' average GPA was 3.25 (SD=0.46), and their average age was 20.96 (SD=2.63).

Measures

Think-aloud protocol analysis (Ericsson 2006; Ericsson & Simon 1994) was used to capture, identify, and analyze participants' use of *monitoring processes* during the hypermedia task. Monitoring variables were individually defined from simple utterance frequencies. A modified coding scheme, originally developed by Azevedo et al. (2008), was used to code participants' verbalizations during the think aloud. This original coding scheme was based on several recent models of SRL (Butler & Winne 1995; Corno & Mandinach 2004; Pintrich 2000; Winne 2001; Winne & Hadwin 1998, 2008; Winne & Perry 2000; Zimmerman 2000, 2001, 2006) as well as extensive SRL and hypermedia research conducted by Azevedo, Moos, Greene, and colleagues (Azevedo 2007, 2008; Azevedo & Witherspoon 2009; Azevedo et al. 2007, 2008; Greene et al. 2008; Moos & Azevedo 2006, 2008a, b, 2009). For the purposes of this study, we used a portion of the coding scheme to examine the following monitoring processes: Monitoring understanding, monitoring environment, monitoring progress towards goal, monitoring use of strategies, and time management (see Appendix A).

In order to measure participants' *prior domain knowledge* and *learning outcomes*, an established pretest and posttest was used. The pretest and posttest, which are identical[2], have been extensively used in previous research (see Azevedo et al. 2006, 2007, 2008; Greene et al. 2008; Moos & Azevedo 2006, 2008a, b) and are based on Chi and colleagues' research (Chi 2000, 2005; Chi et al. 1994). The pretest and posttest are comprised of a mental model essay, which measures conceptual knowledge. Conceptual knowledge is defined as understanding interrelationships between definitions, properties of concepts, and facts, which include declarative and procedural knowledge (Chi 2000, 2005; Graesser et al. 2005; Markman & Gentner 2000). An example of conceptual knowledge in this study includes an understanding of how the different chambers of the heart work together to pump blood throughout the body. The scoring of the mental model essays was examined using Azevedo and colleagues' method (Azevedo & Cromley 2004; Azevedo et al. 2004a, b, 2005, 2006, 2007, 2008), which is based on Chi and colleagues' research (Chi 2000; Chi et al. 1994). The coding scheme consists of 12 mental models, which represent the progression from a low level of understanding to a high level of understanding of the circulatory system (see Table 1). The participants' mental model on the pretest served as an indicator of their prior domain knowledge, while their mental model on the posttest served as an indicator of their learning outcome.

Forty-two (n=42) pretest and posttest mental model essays were used from 21 participants to establish inter-rater reliability for the scoring of these essays. There was agreement on 38 out of a total of 42 scored essays, yielding an inter-rater agreement of 0.90. Disagreements on the scoring of these essays were resolved through discussion.

In order to measure participants' *self-efficacy*, a modified self-efficacy scale from the Motivated for Strategies Learning Questionnaire (MSLQ; Pintrich et al. 1991) was used.

[2] The directions for the mental model essay were as follows: 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

Table 1 Necessary features for each type of mental model (from Azevedo et al. 2008)

1. No understanding
2. Basic global concepts
•Blood circulates
3. Global concepts with purpose
•Blood circulates
•Describes "purpose"—oxygen/nutrient transport
4. Single loop—basic
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
5. Single loop with purpose
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Describe "purpose"
6. Single loop—advanced
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Describe "purpose"
•Mentions one of the following: electrical system, transport functions of blood, details of blood cells
7. Single loop with lungs
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Mentions lungs as a "stop" along the way
•Describe "purpose"
8. Single loop with lungs—advanced
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Mentions Lungs as a "stop" along the way
•Describe "purpose"
•Mentions one of the following: electrical system, transport functions of blood, details of blood cells
9. Double loop concept
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Describes "purpose"
•Mentions separate pulmonary and systemic systems
•Mentions importance of lungs
10. Double loop—basic
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport

Table 1 (continued)

•Describe "purpose"
•Describes loop: heart–body–heart–lungs–heart
11. Double loop—detailed
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Describe "purpose"
•Describes loop: heart–body–heart–lungs–heart
•Structural details described: names vessels, describes flow through valves
12. Double loop—advanced
•Blood circulates
•Heart as pump
•Vessels (arteries/veins) transport
•Describe "purpose"—oxygen/nutrient transport
•Describes loop: heart–body–heart–lungs–heart
•Structural details described: names vessels, describes flow through valves
•Mentions one of the following: electrical system, transport functions of blood, details of blood cells

The self-efficacy scale from the MSLQ includes eight task and context specific questions regarding self-efficacy. The wording of these eight questions was slightly modified in this study to ensure that the questions were specific to the learning task. For example, the question, "I believe I will receive an excellent grade in this course" was modified to, "I believe I will receive an excellent posttest score after learning about the circulatory system with this computer program." Each question is answered on a seven point Likert scale (1=not at all true of me, 7=very true of me). The scoring of these items followed the scoring procedure used for the complete MSLQ (see Pintrich et al. 1991). In this procedure, each participant received one self-efficacy score (possible range=1 to 7). The Cronbach's alpha of 0.93 for this scale with this sample indicated that there was high reliability, which is consistent with previous research that has used this scale from the MSLQ.

Procedure

Each participant was individually tested in a university laboratory during one experimental session which lasted approximately 75 min. After completing the consent form, each participant was given 15 min to complete the pretest. Following the completion of the pretest, each participant was presented with the following instructions for the learning task: "You are being presented with an electronic encyclopedia, which contains textual information, static diagrams, and a digitized video clip of the circulatory system. We are trying to learn more about how students learn from electronic encyclopedia environments, like Encarta. Your task is to learn all you can about the circulatory system in 30 min. 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. In order for us to understand how you learn about the circulatory system, we ask you to "think aloud" continuously while you read and search Encarta. Say everything you are thinking and doing. I'll be here in case anything goes wrong with the computer and the equipment. Please remember that it is very important to say everything that you are thinking and doing while you are working on this task." Following these directions, participants were a given a training session, which involved using the embedded functions and navigating in the hypermedia environment[3]. Participants completed the self-efficacy self-report questionnaire (Pintrich et al. 1991) following this training session. Next, participants engaged in the 30-min hypermedia learning task during which they learned about the circulatory system. During this learning task, the think-aloud protocol was used to capture process data on the monitoring processes used by these participants. Lastly, participants were given 15 min to complete the posttest.

Results

Research Question #1: To what extent is self-efficacy and prior domain knowledge related to the use of specific monitoring processes during learning with hypermedia? To determine these relationships, Pearson correlations between specific monitoring processes, self-efficacy, and prior domain knowledge were calculated (see Table 2 for the mean and standard deviations of specific monitoring processes, self-efficacy, and prior domain knowledge and Table 3 for the correlations between these variables). The correlation analyses revealed significantly detectable positive relationships between self-efficacy and three of the five monitoring variables: *Monitoring Understanding* (r=0.485 p<0.01), *Monitoring Environment* (r=0.389, p=0.01), and *Monitoring Progress Towards Goals* (r=0.384, p<0.01). Additionally, there was a significant correlation between prior domain knowledge and one monitoring variable: *Monitoring Understanding* (r=0.260, p=0.03).

Research Question #2: To what extent is the relationship between self-efficacy and learning outcomes mediated by the use of specific monitoring processes? Regression analyses were conducted to examine whether specific monitoring processes mediated the relationship between self-efficacy and learning outcomes. The monitoring variables used for this research question reflect the significant relationships identified in research question one. As such, three separate regression analyses were run with the following monitoring variables: Monitoring Understanding, Monitoring Environment, and Monitoring Progress Towards Goal. These separate regression analyses were run using conditions put forth by Baron and Kenny (1986). In essence, the following conditions need to be met: (1) The predictor is significantly related to the mediator, (2) the predictor is significantly related to the dependent variable in the absence of the mediator, (3) the mediator has a significant unique relationship with the dependent variable, and (4) the effect of the predictor on the dependent variable becomes smaller upon the addition of the mediator to the model.

The first regression analysis tested whether the variable of Monitoring Understanding mediated the relationship between self-efficacy and learning outcomes. To satisfy the first requirement of Baron and Kenny's (1986) method, regression analysis tested the pathway between the predictor (self-efficacy) and the mediator (Monitoring Understanding). Results indicated that that the relationship between self-efficacy and Monitoring Understanding was significantly detectable, b=0.49, t(66)=4.51, p<0.01. The proportion of variance in Monitoring Understanding explained by self-efficacy was significantly detectable, R^2=0.24, F(1,66)=20.33, p<0.01. To satisfy the second requirement, regression analysis tested the

[3] During the learning task, participants used a commercially-based hypermedia environment, Microsoft Encarta Reference Suite™ (2003). This environment contains multiple representations and numerous hyperlinks. The participants were free to use any of the multiple representations and/or hyperlinks during the 30 min learning task

Table 2 Mean and standard deviation for prior declarative and conceptual knowledge, self-efficacy, and monitoring variables (N=68)

Variable	Mean	Standard deviation
Prior domain knowledge[a]	5.37	2.64
Learning outcome[b]	8.56	3.26
Self-efficacy[c]	4.83	0.96
Monitoring[d]		
Monitoring understanding	4.21	3.92
Monitoring environment	3.13	2.87
Time monitoring	0.25	.61
Monitoring progress towards goals	0.75	1.33
Monitoring use of strategies	0.12	0.47

[a] Possible range=1 to 12

[b] Possible range=1 to 12

[c] Possible range=1 to 7

[d] Mean frequency over 30-min learning task

pathway between the predictor (self-efficacy) and the dependent variable (learning outcome). Results indicated that that the relationship between self-efficacy and learning outcomes as measured by the posttest was significantly detectable, b=0.35, t(66)=3.07, p<0.01. The proportion of variance in learning outcomes explained by self-efficacy was significantly detectable, R^2=0.12, F(1,66)=9.10, p<0.01. The third step for testing mediation involved testing if the relationship between the mediator (Monitoring Understanding) and the dependent variable (learning outcomes) was significantly detectable. Results indicated that that the relationship between Monitoring Understanding and learning outcomes as measured by the posttest was significantly detectable, b=0.38, t(66)=3.38, p<0.01. The proportion of variance in learning outcomes explained by Monitoring Understanding was significantly detectable, R^2=0.15, F(1,66)=11.41, p<0.01. Finally, the relationship between the predictor

Table 3 Correlations between monitoring processes, self-efficacy, prior domain knowledge, and learning outcomes

	1.	2.	3.	4.	5.	6.	7.	8.
1.PDK	–							
2. SE	0.27*	–						
3.LO	0.58**	0.39**	–					
4.MU	0.26*	0.49**	0.38**	–				
5. ME	0.09	0.39**	0.39**	0.44**	–			
6. MPTG	0.21	0.38**	0.30**	0.41**	0.45**	–		
7. TM	−0.16	0.09	0.11	−0.13	0.31**	−0.03	–	
8. MUS	−0.17	0.03	0.15	0.01	0.41**	−0.01	0.26*	–

1. PDK prior domain knowledge; *2. SE* self-efficacy; *3. LO* learning outcomes; *4. MU* monitoring understanding; *5. ME* monitoring environment; *6. MPTG* monitor progress towards goal(s); *7. TM* time monitoring; *8. MUS* monitor use of strategies

*p<0.05; **p<0.01

(self-efficacy) and the dependent variable (learning outcomes) decreased when controlling for the mediator (Monitoring Understanding). Specifically, the partial portion of variance in learning outcomes explained by self-efficacy was not significant in this model ($R^2=0.03$; $p=0.10$), and the results also indicated that that the relationship between self-efficacy and learning outcomes was not significantly detectable in this model, $b=0.21$, $t(65)=1.649$, $p=0.10$. Because these results suggest that all conditions of meditation were met, as proposed by Baron and Kenny's (1986) method, it was concluded that the relationship between self-efficacy and learning outcomes was mediated by the frequency in which participants monitored their understanding.

The second regression analysis tested whether the variable of Monitoring Environment mediated the relationship between self-efficacy and learning outcomes. First, the regression analysis tested the pathway between the predictor (self-efficacy) and the mediator (Monitoring Environment). Results indicated that that the relationship between Monitoring Environment and self-efficacy was significantly detectable, $b=0.39$, $t(66)=3.43$, $p<0.01$. The proportion of variance in Monitoring Environment explained by self-efficacy was significantly detectable, $R^2=0.15$, $F(1,66)=11.76$, $p<0.01$. To satisfy the second requirement, regression analysis tested the pathway between the predictor (self-efficacy) and the dependent variable (learning outcome). Results indicated that that the relationship between self-efficacy and learning outcomes as measured by the posttest was significantly detectable, $b=0.35$, $t(66)=3.07$, $p<0.01$. The proportion of variance in learning outcomes explained by self-efficacy was significantly detectable, $R^2=0.12$, $F(1,66)=9.10$, $p<0.01$. The third step for testing mediation involved testing if the relationship between the mediator (Monitoring Environment) and the dependent variable (learning outcomes) was significantly detectable. Results indicated that that the relationship between Monitoring Environment and learning outcomes as measured by the posttest was significantly detectable, $b=0.39$, $t(66)=3.48$, $p<0.01$. The proportion of variance in learning outcomes explained by Monitoring Environment was significantly detectable, $R^2=0.16$, $F(1,66)=12.11$, $p<0.01$. Finally, the relationship between the predictor (self-efficacy) and the dependent variable (learning outcomes) decreased when controlling for the mediator (Monitoring Environment). Specifically, the partial portion of variance in learning outcomes explained by self-efficacy was not significant in this model ($R^2=0.05$; $p=0.06$), and the results also indicated that that the relationship between self-efficacy and learning outcomes was not significantly detectable in this model, $b=0.23$, $t(65)=1.91$, $p=0.06$. Because these results suggest that all conditions of meditation were met as proposed by Baron and Kenny's (1986) method, it was concluded that the relationship between self-efficacy and learning outcomes was significantly mediated by the frequency in which the participants monitored the environment.

The third regression analysis tested whether the variable of Monitoring Progress Towards Goal mediated the relationship between self-efficacy and learning outcomes. First, the regression analysis tested the pathway between the predictor (self-efficacy) and the mediator (Monitoring Progress Towards Goal). Results indicated that that the relationship between self-efficacy and Monitoring Progress Towards Goal was significantly detectable, $b=0.38$, $t(66)=3.38$, $p<0.01$. The proportion of variance in Monitoring Progress Towards Goal explained by self-efficacy was significantly detectable, $R^2=0.15$, $F(1,66)=11.43$, $p<0.01$. To satisfy the second requirement, regression analyses tested the pathway between the predictor (self-efficacy) and the dependent variable (learning outcome). Results indicated that that the relationship between self-efficacy and learning outcomes as measured by the posttest was significantly detectable, $b=0.35$, $t(66)=3.07$, $p<0.01$. The proportion of variance in learning outcomes explained by self-efficacy was significantly detectable, R^2=0.12, $F(1,66)=9.10$, $p<0.01$. The third step for testing mediation involved testing if the mediator (Monitoring Progress Towards Goal) was significantly associated with the dependent variable (learning outcomes). Results indicated that that the relationship between Monitoring Progress Towards Goal and learning outcomes as measured by the posttest was significantly detectable, $b=0.30$, $t(66)=2.53$, $p=0.01$. The proportion of variance in learning outcomes explained by Monitoring Progress Towards Goal was significantly detectable, $R^2=0.09$, $F(1,66)=6.40$, $p=0.01$. However, the relationship between the predictor (self-efficacy) and the dependent variable (learning outcomes) did not significantly decrease when controlling for the mediator (Monitoring Progress Towards Goal). Specifically, the partial portion of variance in learning outcomes explained by self-efficacy was significant in this model ($R^2=0.06$; $p=0.03$), and the results also indicated that that the relationship between self-efficacy and learning outcomes was significantly detectable in this model, $b=0.27$, $t(65)=2.2218$, $p=0.03$. This last result suggests that while both self-efficacy and Monitoring Progress Towards Goal were significantly related to learning outcomes, Monitoring Progress Towards Goal did not significantly mediate the relationship between self-efficacy and learning outcomes.

Research Question #3: To what extent is the relationship between prior domain knowledge and learning outcomes mediated by the use of specific monitoring processes? The monitoring variable used for this research question reflects the significant relationships identified in research question one. As such, one meditational analysis was run with the variable of Monitoring Understanding. First, the regression analysis tested the pathway between the predictor (prior domain knowledge) and the mediator (Monitoring Understanding). Results indicated that that the relationship between prior domain knowledge and Monitoring Understanding was significantly detectable, $b=0.26$, $t(66)=2.19$, $p=0.03$. The proportion of variance in Monitoring Understanding explained by prior domain knowledge was significantly detectable, $R^2=0.07$, $F(1,66)=4.80$, $p=0.03$. To satisfy the second requirement, regression analyses tested the pathway between the predictor (prior domain knowledge) and the dependent variable (learning outcome). Results indicated that that the relationship between prior domain knowledge and learning outcomes as measured by the posttest was significantly detectable, $b=0.58$, $t(66)=5.71$, $p<0.01$. The proportion of variance in learning outcomes explained by prior domain knowledge was significantly detectable, $R^2=0.33$, $F(1,66)=32.60$, $p<0.01$. The third step for testing mediation involved testing if the mediator (Monitoring Understanding) was significantly associated with the dependent variable (learning outcomes). Results indicated that that the relationship between Monitoring Understanding and learning outcomes as measured by the posttest was significantly detectable, $b=0.38$, $t(66)=3.38$, $p<0.01$. The proportion of variance in learning outcomes explained by Monitoring Understanding was significantly detectable, $R^2=0.15$, $F(1,66)=11.41$, $p<0.01$. However, the relationship between the predictor (prior domain knowledge) and the dependent variable (learning outcomes) did not decrease when controlling for the mediator (Monitoring Understanding). Specifically, the partial portion of variance in learning outcomes explained by prior domain knowledge was significant in this model ($R^2=0.23$; $p<0.01$), and the results also indicated that that the relationship between prior domain knowledge and learning outcomes was significantly detectable in this model, $b=0.51$, $t(65)=5.08$, $p<0.01$. This last result suggests that while prior domain knowledge and Monitoring Understanding were significantly related to learning outcomes, Monitoring Understanding did not significantly mediate the relationship between prior domain knowledge and learning outcomes.

Discussion

Previous research has indicated that learners are often faced with metacognitive demands when learning with hypermedia (see Azevedo 2005, 2008, 2009; Schraw 2007; Veenman 2007). Though recent research has used process data to empirically demonstrate the importance of micro-level monitoring processes related to metacognition (e.g., Azevedo et al. 2007, 2008; Azevedo & Witherspoon 2009; Greene & Azevedo 2009, 2008; Moos & Azevedo 2008a), this line of research has focused on the direct relationship of these processes on learning outcomes without considering the possibility that these processes act as mediating variables. This current study attempted to address this issue by capitalizing on previous research and examining the extent to which specific monitoring processes act as mediator variables between both self-efficacy and prior domain knowledge on learning outcomes with hypermedia. The following discussion will first examine each research question. Following this discussion, pertinent future directions and the limitations of this study will be addressed.

Results from the first research question indicated that self-efficacy was positively related to specific monitoring processes, including *Monitoring Understanding, Monitoring Environment,* and *Monitoring Progress Towards Goal*. This finding is consistent with previous research in the broadest sense. Previous research has routinely demonstrated that self-efficacy is a strong predictor of various processes of learning. For example, Bouffard-Bouchard et al. (1991) found that high school students with lower self-efficacy did not persist as long as students with higher self-efficacy during problem solving. Furthemore, Wigfield and Guthrie (1997) found that self-efficacy has a significant positive correlation with 4th and 5th graders' breadth of their reading and the time that they took to read outside of school. Additionally, Zimmerman and Bandura (1994) demonstrated that self-efficacy is also related to students' vigor towards a task as evidenced by results indicating that self-efficacy for writing was positively correlated with college students' goals for course achievement, among other things. However, it should be noted these studies focused on the relationship between self-efficacy and persistence, vigor, and breadth of reading. It is our understanding that limited previous research has used process data (i.e. think-aloud protocols) to examine the relationship between self-efficacy and the use of monitoring processes during learning.

Additionally, results from research question one also indicated that prior domain knowledge is significantly related to the use of monitoring processes, in particular *Monitoring Understanding*. While previous research has indicated that prior domain knowledge is a powerful predictor in learning (Alexander 2003; Alexander & Murphy 1998; Alexander & Jetton 2003; Dochy & Alexander 1995; Schraw 2007), there has been limited empirical research that has used process data to explain why prior domain knowledge may be such a powerful predictor. This current study contributes to the literature by suggesting that prior domain knowledge is related to the use of monitoring processes, which is consistent with some previous research. For example, Moos and Azevedo (2008a) found that learners with higher prior domain knowledge deploy monitoring processes during learning with hypermedia, while learners with lower prior domain knowledge primarily deploy strategies during learning.

This current study, coupled with previous research, suggests that learners with higher prior domain knowledge may be better equipped to use monitoring processes when learning with hypermedia. In particular, hypermedia offers a nonlinear environment that requires decisions about which information to access (Azevedo 2005; Lawless & Brown 1997; Shapiro 1999; Williams 1996). Learners with limited prior domain knowledge have little to guide their decision about the sequential path, while learners with higher prior domain knowledge have a more developed understanding of the conceptual structure of the domain

(Chen et al., 2006). As such, learners with higher prior domain knowledge are more likely to *monitor their understanding* when learning with hypermedia, which is consistent with findings from this current study. These learners may be more likely to monitor their understanding because they do not have to build an understanding of the topic due to their prior knowledge. Therefore, they can allocate more cognitive resources to monitor what they know and do not know as they interact with the hypermedia learning environment.

Results from research question one identified which specific monitoring processes were related to self-efficacy and prior domain knowledge. This result guided the analysis for research questions two and three, which examined the extent to which specific monitoring processes acted as mediator variables between both self-efficacy and prior domain knowledge and learning outcomes. Regressions run using Baron and Kenny's (1986) method indicated that the relationship between self-efficacy and learning outcomes was mediated by the extent to which participants monitored their understanding and monitored the environment. The positive relationship between these variables indicated that participants who were more efficacious tended to use more monitoring processes related to *Monitoring Understanding* and *Monitoring Environment*, which in turn was positively related to learning outcomes. In many ways, this finding highlights and fills in some missing holes in previous research. The importance of monitoring processes while learning with hypermedia has been well document (Azevedo 2007, 2008; Azevedo et al. 2004a, b; Greene & Azevedo 2007, 2009). In order to effectively make decisions with hypermedia, learners need to: (1) examine the relevancy of the content with respect to the overall learning goal (i.e. "monitor environment"); *and* (2) consider the extent to which they have already developed conceptual knowledge of the particular content (i.e. "monitor understanding"). While the importance of these two processes has been well-documented, the examination of these processes should be broadened to consider the relationship with other important processes in learning with hypermedia, including prior domain knowledge and self-efficacy. This current study begins to shed light on these complex relationships and is consistent with previous research.

For example, Rheinberg et al. (2000) suggest that learners may monitor the links between the desired outcomes and their actions. Monitoring processes allow learners to determine if there is a discrepancy between the desired outcomes and their actions (Butler & Winne 1995; Winne 2001; Winne & Hadwin 1998, 2008). If a discrepancy is noted through monitoring processes, learners may modify learning processes to better enable themselves to meet the goal of the learning activity (Winne 2001; Winne & Hadwin 1998). However, there is a certain "cognitive cost" in modifying and enacting these learning processes. Engaging in effortful processes related to monitoring may consume a substantial portion of working memory. The results of this study suggest that a learner may decide to enact these monitoring processes *only if* the learner is efficacious (i.e. is confident about his/her capability to accomplish the specific task in this study; Bandura 1986, 1994, 1997; Schunk 1984, 1991; Wood & Bandura 1989). This explanation suggests that learners may undertake a "cost–benefit" analysis when enacting SRL processes related to monitoring. The cost of using effortful SRL processes will be perceived as outweighed by the benefit of using these processes *only if* the learner is efficacious.

Future Directions

While this current study adds to the current literature on the complex relationships between monitoring, self-efficacy, and prior domain knowledge, there are three promising directions for future research. First, one promising direction for future research is to consider the accuracy of learners' monitoring processes (Azevedo 2009; Pieschl 2009; Schraw 2009). According to the information processing view of self-regulation, learners will adapt their strategies, plans, and other learning processes if a discrepancy is revealed between the learning goal(s) and learners' current knowledge state (Winne 2001). This discrepancy is revealed through various monitoring processes. If, on the other hand, monitoring processes suggest that a discrepancy does not exist, then learners are unlikely to adapt and/or alter their strategies, plans, and other learning processes (Winne 2001). These assumptions indicate that inaccurate monitoring processes may result in less than ideal approaches to the learning task. Thus, identifying the accuracy of learners' monitoring is critical to understanding the complex nature between metacognition and learning outcomes. However, it should be noted that this current study did not measure the accuracy of these processes, an issue further examined in the Limitations section.

Second, future research should also consider the effect of the structure within a hypermedia environment, in addition to considering learner characteristics such as the ability to accurately use monitoring processes. As identified by Schwartz et al. (2004), the relationship between monitoring processes and learning is related to the structure of the hypermedia environment. Hypermedia environments that contain an unfamiliar structure require metacognitive knowledge and, in some cases, may overload working memory due to the metacognitive demands of such a structure (Schwartz et al. 2004). Conversely, hypermedia environments that use "recognizable conventions", such as an outline format, may place limited metacognitive demands on working memory (Schwartz et al. 2004). While this line of research has provided substantial contributions to the field, it should be noted that these studies typically used self-report questionnaires to collect data on metacognition (e.g., Junior Metacognitive Awareness Inventory; Sperling et al. 2002). Future research would benefit from also using process data (i.e. think-aloud protocols; Ericsson 2006; Ericsson & Simon 1994).

Third, it should be noted that this current study did not measure cognitive load, a construct that has received considerable attention in research on multimedia and hypermedia (DeLeeuw & Mayer 2008). Research examining monitoring processes with hypermedia is particularly concerned with extraneous cognitive load, which can be imposed upon working memory when learners are faced with multiple sources of information in the hypermedia environment (Gerjets & Scheiter 2003; Kester et al. 2005; Scott & Schwartz 2007; Sweller 2004). Measuring cognitive load, in addition to measuring monitoring processes with process data, will allow for a more comprehensive understanding of the complex interrelationship between the structure of the environment and learning processes.

Limitations

There are several limitations that need to be identified, some of which can be addressed in future research. First, the content area of this current study was limited, and thus the generalizability of the findings is also limited. Future research would be well served to examine other content areas, including more ill-defined topics. Additionally, this study examined undergraduates' use of monitoring processes. However, several researchers have identified developmental differences (e.g., Greene et al. 2008). This line of research identified *what* monitoring processes different developmental groups use when learning with hypermedia. Extending this current study to examine various developmental groups will provide information on *why* different developmental groups use monitoring processes during learning with hypermedia. Lastly, it should be noted that the unit of analysis was the *frequency* with which the participants used monitoring processes. Clearly, the *quality* (i.e.

accuracy) of these processes should be considered. In particular, the calibration of the monitoring processes should be considered because inaccurate monitoring processes could negatively affect the learning outcomes (Pieschl 2009; Schraw 2009). For example, if a learner incorrectly believes that the content of the environment is not relevant (i.e. "Monitoring Environment"), then the learner may be more likely to minimize their exposure to important information during learning. However, it should be noted that there are logistical concerns for diagnosing the accuracy of some monitoring processes, particularly "Monitoring Understanding." In order to identify the accurate use of this monitoring variable, there would need to be an on-line, real time diagnosis of the learner's knowledge state. This diagnosis would be needed to determine if the learner is making accurate interpretations regarding their emerging understanding. Designing such diagnosis tools is certainly a challenge for future research, but the relationship between the quality of the monitoring variables and learning outcomes with hypermedia is an important and largely unexplored area.

Appendix A: SRL coding scheme

Table 4 Classes, descriptions and examples of the variables used to code students' regulatory behavior (modified version from Azevedo et al. 2008)

Variable Monitoring	Description	Student examples
Monitoring environment	Stating that text, diagram, or video is relevant and/or irrelevant	[Learner reads about red blood cells] "This is just what I was looking for." "I'm reading through the info but it's not specific enough for what I'm looking for."
Monitoring understanding	Indicating a level of familiarity with content in the environment. Also, includes indications of the extent to which there is an understanding of what was just read/seen in the environment.	"Oh, I already read that." "I didn't know that." "Okay, this makes sense." "Wait, this isn't making any sense."
Monitor progress toward goals	Assessing whether previously-set goal has been met	"Those were our goals, and I think I am accomplishing them."
Monitor use of strategies	Commenting on usefulness of strategy	"Yeah, drawing really helped me understand how blood flow throughout the heart."
Time monitoring	Referring to the number of minutes remaining	"Wow. I only have 10 minutes left."

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