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Issues in the Measurement of Cognitive and Metacognitive Regulatory Processes Used During Hypermedia Learning

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Abstract

The goal of this paper is to present four key assumptions regarding the measurement of cognitive and metacognitive regulatory processes used during learning with hypermedia. First, we assume it is possible to detect, trace, model, and foster SRL processes during learning with hypermedia. Second, understanding the complex nature of the regulatory processes during learning with hypermedia is critical in determining why certain processes are used throughout a learning task. Third, it is assumed that the use of SRL processes can dynamically change over time and that they are cyclical in nature (influenced by internal and external conditions and feedback mechanisms). Fourth, capturing, identifying, and classifying SRL processes used during learning with hypermedia is a rather challenging task.

1. Introduction

Learning with open-ended learning environments such as hypermedia typically involves the use of numerous self-regulatory processes such as planning, knowledge activation, metacognitive monitoring and regulation, and reflection (Azevedo 2005, 2008; Graesser et al. 2005; Greene & Azevedo, 2009; Moos & Azevedo, in press; Schraw 2007; Veenman, 2007; Winne & Nesbit, in press; Zimmerman 2008). According to Pintrich (2000), self-regulated learning (SRL) is an active, constructive process whereby students set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior guided and constrained by their goals and the contextual features in the environment. Most models of SRL propose a general time-ordered sequence that students follow as they perform a task, but there is no strong assumption that the various phases (such as planning, monitoring, control, and reflection) are hierarchically or linearly structured such that earlier phases must occur before later phases (see e.g., Ainley & Patrick 2006; Azevedo, 2009; Azevedo & Witherspoon, in press; Boekaerts et al. 2000; Efklides 2008; Greene and Azevedo 2007; Pintrich 2000; Schraw 2006; Schraw & Moshman 1995; Schunk, 2001, 2005; Winne, 2001; Winne & Hadwin 1998, 2008; Zimmerman, 1989, 2001, 2006, 2008; Zimmerman & Schunk 2001). While most theories, models, and frameworks of SRL tend to agree on some common basic assumptions (e.g., students are actively constructing knowledge, contextual factors mediate one's ability to regualte aspects of learning), they also differ in some fundamental issues regarding the nature of SRL (e.g., aptitude vs event, role of various contexttual agents, number and types of processes, specificity of the underlying internal and external mechanisms, explanatory adequacy; see Schunk & Zimmerman, 2001, in press). These discrepancies pose problems for those interested in understanding and measuring regulatory processes during learning with hypermedia (see Azevedo, 2005, 2007, 2009; Greene & Azevedo, 2007, 2009; Moos & Azevedo, 2008a, in press). The purpose of this paper is not resolve this long-standing debate. The goal of this paper is to focus on some of the theroetical, conceptual, and methodological issues related to measuring the cognitve and metacognitive regualtory processes during learning with hypermedia environments.

2. Self-Regulated Learning (SRL) with Hypermedia

The complex nature of SRL can be understood by providing an example of learning with hypermedia. Imagine a student is asked to learn about the human cardiovascular system with an open-ended hypermedia learning environment that contains several hundred static diagrams, hundreds of paragraphs containing thousands of words with corresponding static diagrams and video clips all of which may be organized is some fashion (similar to text chapters) and hundreds of hyperlinks allowing the students to navigate freely throughout the environment. One could imagine this self-regulated learner would analyze the learning situation, set meaningful sub-goals, and determine which strategies to use based on the task conditions. In addition, the student may generate motivational beliefs based on prior experience with the topic and learning environment, success with similar tasks, contextual constraints (e.g., provision of scaffolding and feedback by the hypermedia environment or human or artificial agent) and contextual demands (e.g., a time limit for completion of the task). During the course of learning, the student may assess whether particular strategies are effective in meeting his learning sub-goals, evaluate his emerging understanding of the topic, and make the necessary adjustments regarding his knowledge, behavior, effort, and other aspects of the learning context. The adaptive adjustments, based on continuous metacognitive monitoring and control related to the standards for the particular learning task, facilitate decisions regarding when, how, and what to regulate (Winne 2001, 2005; Winne & Hadwin, 2008; Zimmerman, 2006). Following the learning session, he may make several cognitive, motivational, and behavioral attributions that affect subsequent learning (Pintrich 2000). This scenario represents a prototypical approach to self-regulating one's learning with hypermedia.

3. Understanding the complex nature of SRL: Considering fundamental assumptions

Measuring cognitive and metacognitive processes during learning with hypermedia

It has become increasingly important for researchers to understand the complex nature of the underlying self-regulatory processes that facilitate learning from open-ended learning environments such as hypermedia. The example described above is used to illustrate the intricate nature of the metacognitive monitoring and regulatory processes used during learning. While we acknowledge the fundamental role of other key physiological, motivation, affective, and social processes self-regulatory processes, in this paper we focus exclusively on cognitive and metacognitive processes during learning with hypermedia environments. However, a consideration of these processes requires a close examination of the fundamental assumptions regarding measurement.

First, we assume that is it possible to *detect, trace, model, and foster SRL processes during learning*. These assumptions are based on decades of cognitive psychology research using on-line trace methodologies such as eye-tracking, concurrent think-aloud protocols, keystroke analysis, and cognitive modeling in various domains across school and professional domains. Each of these techniques make fundamental assumptions regarding the role of cognitive, metacognitive, behavioral, neural, and rational processes during learning, skill acquisition, and performance (see Anderson & Labiere, 1998; Ericsson, 1993, 2006; Newell, 1990; Newell & Simon, 1972). In our research, we have adopted several of these key methodologies to capture the deployment of SRL processes during learning. Therefore, we make a fundamental assumption that cognitive and metacognitive regulatory processes can be detected and traced during learning. This is accomplished by using a combination of concurrent think-aloud protocols, video and audio time-stamp data, and log-file data all captured during learning with hypermedia. It should be noted that the SRL processes captured with these methods is a direct reflection of the nature of the analytical tools and that other on-line trace methodologies (e.g., eye-tracking, error detection) would provide additional data and perhaps reveal the deployment of other cognitive and metacognitive SRL processes such as micro-level understanding of the integration of specific aspects of the text and diagram that are being integrated into a coherent mental model. It is also important to highlight that no one methodology can capture all of the processes and that under some conditions it is unwise to use some of these methods (e.g., using concurrent think-aloud protocols for purely perceptual tasks or using concurrent think-aloud protocols to examine SRL in experts solving typical problems). The key is to converge evidence from various analytical methods to measure the deployment of cognitive and metacognitive processes. These various methodologies will be furthered explored in the next section.

Second, understanding the complex nature of the regulatory processes during learning with hypermedia is critical in *determining why certain processes are used* (i.e., what decisions did a student make that led to the deployment of a particular process, set of processes, absence of processes, and/or repeating patterns of processes that may fluctuate during the learning). These questions deal with the role of agency (Bandura, 1986), self-efficacy (Moos & Azevedo, 2008, in press), adaptivity, developmental differences in regulating learning, task perceptions and several other issues found in the literature. Additionally, these question address the following: (1) whether learners use/did not use certain processes because they had the metacognitive knowledge but they could not translate that knowledge into regulatory control, perhaps because their perception that particular cognitive and metacognitive processes are too difficult or they do not have the conditional knowledge to determine when to use the SRL process; (2) lack of experience with the cognitive and metacognitive strategies; (3) they may have low self-efficacy in using such processes, (4) fail to encode some critical aspect of the task environment or fail to continuously and dynamically model changes in the task environments leading to a poor task understanding, (5) there may also be a lack of appropriate internal standards (or no standards at all for a new task with new demands), (6) failure to properly identify and register conditions, (7) there may a cognitive or motivational explanation limiting the student's capability to execute the necessary regulatory processes; and, (8) the hypermedia learning environment may afford the learner the ability to deploy the necessary regulatory processes (see Azevedo & Witherspoon, in press; Winne, 2005; Winne & Nisbett, in press). Addressing these complex decisions that determine the extent to which learners' engage in SRL is critical in determining the explanatory adequacy of SRL models. It is important to note, however, that these models will vary based on the researcher's theoretical orientation and analytical methods.

Third, it is assumed that can the use of SRL processes can *dynamically change over time* and that they are *cyclical in nature* (Azevedo & Witherspoon, in press; Schunk, 2001; Winne, 2001; Winne & Perry, 2000; Zimmerman, 2008). This assumption is based on notion that SRL processes are not only deployed in real-time but that they fluctuate in terms of frequency depending on the learning task (e.g., more planning processes at the beginning of a learning task, almost constant use of metacognition monitoring processes throughout the task). The learners' level of domain expertise is also critical in the observed use of specific learning strategies such as a sharp decrease from beginning to the end of a task for a learning strategy such as note taking and drawing. Some metacognitive monitoring processes such as judgments of learning (JOLs) and feeling of knowing (FOKs) tend to deployed at the same rate during a learning session. Other processes tend to occur very infrequently because the learning environment has been designed in such a manner that it prohibits or facilitates the deployment of particular strategies. For example, there are fewer occurrences of content evaluation (a metacognitive judgment made when one compares the content of the hypermedia learning environment to one's current goal) in a hypermedia environment that has been designed so that diagrams are only accessible when one commits reading the text.

Over the course of learning, learners *leave a trace of SRL processes* that may reflect their emerging understanding of the content, development or changes in internal standards, motivational beliefs and attribution, understanding of the dynamic changes of the learning context, and particular phases of learning (e.g., acquisition, retention, and retrieval, see Dunloksy, Serra, & Baker, 2007). These traces can be analyzed in several ways and are informative in determining the qualitative and quantitative changes in SRL processes. For example, are particular SRL processes associated with knowledge acquisition vs. knowledge integration? If so, what would models of SRL predict? For example, Zimmerman and Schunk's (2001) socio-cognitive model would predict that there would be more planning at the beginning of the task, but does this hold if the task is dynamical and cyclical (Schunk, 2005, Winne, 2001)? If so, then when does one cycle end and another begin? What determines the onset of an SRL cycle? Is it knowledge acquisition phases, SRL phases (planning, monitoring, control, and reflection), internal cognitive changes (e.g., changes in goal setting, knowledge acquisition, standards), changes in contextual conditions (e.g., running out of time to complete the task), fluctuations in motivational (e.g., increasing effort after realizing that one is completing goals in a timely manner) and affective (e.g., feeling confused after reading a complex paragraph) processes, etc. So, these traces provide both qualitative and quantitative data that should be mined with various statistical techniques to understand the evolvement of learners' SRL behavior. Recent work on state-transition analysis is currently being performed with machine learning techniques (e.g., Baker et al., 2009; Biswas et al., 2008; Rus, Lintean, & Azevedo, 2009; Witherspoon, Azevedo, & D'Mello, 2008). Lastly, as Winne & Nisbett (in press) state, these fluctuations can be modeled as production rules which can then be embedded in intelligent learning environments to model and foster learners' SRL with hypermedia (e.g., Azevedo et al., 2008, 2009). These types of analyses are furthered explored in the following section.

Fourth, capturing, identifying, and classifying SRL processes used during learning with hypermedia is a rather *challenging* task. Concurrent think-aloud protocols are the premier tool used to capture, analyze, and classify SRL processes. This method needs to be augmented with other methods such as time-tamped video data and log-file data to get the precision needed to classify SRL processes at several levels of granularity. Those using these techniques have created coding schemes that differ in the following ways: complexity, level of granularity complexity, developmental differences, task- or topic-dependent, and they all reflect the researcher's theoretical orientation (for examples see Azevedo et al., 2008; Bannert, 2008; Manlove et al., 2007; Hadwin et al., 2005; Narciss, 2009; Pieschl et al., 2008; Whitebeard et al., 2009). For example, some have a few higher-order categories to capture macro-level aspects of metacognition and SRL (e.g., planning, monitoring, learning strategies) while others include micro-level aspects (e.g., judgment of learning, feeling of knowing, hypothesizing, creating sub-goals). We have recently added valence to our monitoring and learning strategies to further examine the feedback mechanisms associated with SRL during learning. For example, according to Azevedo and colleagues' work (see Azevedo, 2008; Azevedo & Witherspoon, in press) any classification can be accomplished at different levels of granularity: (a) macro-level (e.g., monitoring process), and micro-level (e.g., JOL) with associated valence (either + or −). However, it should be noted that other classification systems and associated analytical approaches and statistical analyses yield different metacognitive indices (e.g., see Benjamin & Diaz, 2008; Greene & Azevedo, 2009; Pieschl, 2009; Schraw, 2009; Van Overschelde, 2008). The same can be done for learning strategies (e.g., correct summarization vs. incorrect summarization). The addition of valence allows us to examine the feedback mechanisms and the nature of the linear and recursive feedback loops during SRL and test predictions based on current models.

For example, according to several models of SRL, metacognitive monitoring precedes metacognitive control if the learner is engaged in goal-driven learning. So, this would allow one to hypothesize that a metacognitive judgment that one does not understand what he just read (i.e., a negative judgment of learning [JOL-]) should be followed by a learning strategy such as re-reading. After re-reading the learner may perhaps judge that he now understands the paragraph (i.e., a JOL+), and so on. What about if the learner still did not understand the paragraph after re-reading it? What should he do next? Would he re-read again? If so, this would perhaps lead into a maladaptive SRL cycle that may lead to frustration or continued confusion. We argue that tracing the temporal unfolding of these SRL processes is key to understanding the nature of SRL processes, their inter-relationships, adaptive vs. maladaptive processes, nature of the cycles, and test predictions based on current models of SRL. The following section will address methodologies that are consistent with the assumptions outlined in this section

A more peculiar situation occurs if researchers decide to add valence to processes related to planning as relevant/irrelevant sub-goal for a task. From an objective perspective a learners' sub-goal can be classified based on its correspondence to the overall learning goal; however, it may erroneously classified as irrelevant if it is fact relevant from the learners' goals, perceived task understanding, and motivations. Lastly, the classification of SRL processes are based on a researcher's inferences regarding what is verbally and (overtly and/or covertly) behaviorally observed in the trace data.

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