Invited Papers

Dysregulated Learning with Advanced Learning Technologies

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Successful learning with advanced learning technologies is based on the premise that learners adaptively regulate their cognitive and metacognitive behaviors during learning. However, there is abundant empirical evidence that suggests that learners typically do not adaptively modify their behavior, thus suggesting that they engage in what is called dysregulated behavior. Dysregulated learning is a new term that is used to describe a class of behaviors that learners use that lead to minimal learning. Examples of dysregulated learning include failures to: (1) encode contextual demands, (2) deploy effective learning strategies, (3) modify and update internal standards, (4) deal with the dynamic nature of the task, (5) metacognitively monitor the use of strategies and make accurate metacognitive judgments, and (6) intelligently adapt behavior during learning so as to maximize learning and understanding of the instructional material. Understanding behaviors associated with dysregulated learning is critical since it has implications for

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determining what they are, when they occur, how often they occur, and how they can be corrected during learning.
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1 Introduction

Successful learning with advanced learning technologies is based on the premise that learners adaptively regulate their cognitive and metacognitive behaviors during learning (Aleven *et al.*, 2010; Azevedo *et al.*, 2010a; Winne, 2011). However, there is abundant empirical evidence that suggests that learners typically do not adaptively modify their behavior, thus suggesting that they engage in what is called dysregulated behavior. Dysregulated learning is a new term that is used to describe a class of behaviors that learners use that lead to minimal learning. Examples of dysregulated learning include failures to: (1) encode contextual demands (e.g., retain an internal mental representation of the hierarchical structure of the learning environment), (2) deploy effective learning strategies (e.g., note-taking and knowledge elaboration), (3) modify and update internal standards, (4) deal with the dynamic nature of the task (e.g., internalize and correct behavior based on the learning system's feedback and scaffolding), (5) metacognitive monitor the use of strategies and make accurate metacognitive judgments, and (6) intelligently adapt behavior during learning so as to maximize learning and understanding of the instructional material. Understanding behaviors associated with dysregulated learning is critical since it has implications for determining what they are (i.e., detection and classification), when they occur (e.g., onset, duration, temporal dynamics, antecedents), how often they occur (e.g., patterns across time, maladaptivity), and how they can be corrected during learning (e.g., inference based on converging evidence, system intelligence, scaffolding, and feedback). The goal of this paper is to: (1) present MetaTutor, an adaptive intelligent multi-agent learning environment designed to train and foster students' SRL and content understanding; (2) present empirically-based examples of dysregualted and regulated learning; and, (3) present some challenges for future directions.

2 MetaTutor: An Adaptive Multi-Agent Intelligent Hypermedia Learning Environment

MetaTutor is a hypermedia learning environment that is designed to detect, model, trace, and foster students' self-regulated learning about human body systems such as the circulatory, digestive, and nervous systems (Azevedo *et al.,* 2009; 2010a; 2010b; 2011). Theoretically, it is based on a general premise of SRL as an event (Azevedo *et al.,* 2011) and on cognitive models of SRL

(Pintrich, 2000; Schunk, 2005; Winne & Hadwin 2008; Zimmerman, 2008). The underlying assumption of MetaTutor is that students should regulate key cognitive and metacognitive processes in order to learn about complex and challenging science topics. The design of MetaTutor is based on our extensive research (see Azevedo, 2008; Azevedo *et al.,* in press a; in press b; Azevedo & Witherspoon, 2009) showing that providing adaptive human scaffolding that addresses both the domain knowledge and the processes of SRL enhances students' learning science topics with hypermedia. Overall, our research has identified key self-regulatory processes that are indicative of students' learning about these complex science topics (Azevedo & Witherspoon, 2009). More specifically, they include several processes related to planning, metacognitive monitoring, learning strategies, and methods of handling task difficulties and demands.

Overall, there are several phases to using MetaTutor to train students on SRL processes and to learn about the various human body systems: (1) a facility that models key SRL processes; (2) a discrimination task where learners choose between good and poor use of these processes; (3) a detection task where learners watch video clips of human agents engaging in similar learning tasks, stop the video whenever they see an SRL process used, and select the relevant process from a list; and (4) the actual learning environment used to learn about the biological system.

The interface of the actual learning environment includes a window dedicated to declaring the learning goal, set by either an experimenter or teacher. For example, "Your task is to learn all you can about the circulatory system. Make sure you know about its components, how they work together, and how they support the healthy functioning of the human body." This goal is associated with the sub-goals window where the learner can generate several sub-goals for the learning session. A list of topics and sub-topics is presented on the left side of the screen, while the actual science content (including the text and diagrammatic representations of information) is presented in the center of the interface. The main communication dialogue window (between the learner and the environment) is displayed directly below the content window. The pedagogical agents are displayed on the top right-hand corner of the interface. Below the agent window is a list of SRL processes that the learner can use throughout the session. Learners can choose to use any SRL process they would like to use at any point during learning by selecting it from the list. The purpose of having learners select the processes is to enhance metacognitive awareness of the processes used during learning and to facilitate the environment's ability to trace, model, and foster learning. In addition to learner-initiated self-regulation, the agent can prompt learners to engage in planning, monitoring, or strategy use under appropriate conditions traced by MetaTutor.

One objective of the MetaTutor system has been to examine the effectiveness of pedagogical agents as external regulatory agents designed to detect, trace, model, and foster students' self-regulatory processes. MetaTutor is in its infancy, so the algorithms to guide feedback to the student are developed but not yet fully tested. The broad scope of SRL appeals to educational researchers who seek to understand how students become adept and independent in their educational pursuits. Whether SRL is viewed as a set of skills that can be taught explicitly or as developmental processes that emerge with experience, pedagogical agents have the potential to provide students of all ages with information that will help them become strategic, motivated, and independent learners. However, several theoretical and empirical issues need further research before practical classroom applications can be put forth (Graesser *et al.,* 2008; Greene, Moos, & Azevedo, in press). How do students regulate their own learning when using a computer-based learning environment (CBLE) to learn complex science topics? Which processes associated with self-regulation and co-regulation do students and pedagogical agents use during collaborative learning with a CBLE? How can pedagogical agents be designed and used in CBLEs to support SRL? How can pedagogical agents be used as external regulating agents that model specific self-regulatory processes and challenge students to use and develop their own?

3 Ideal Self-Regulated Learning

Self-regulated learning (SRL) with non-linear, multi-agent, intelligent, open-ended learning environments like MetaTutor involves using different processes like planning, knowledge activation, metacognitive monitoring and control, strategy use and reflection (Azevedo *at al.*, 2010a). Unfortunately, there is abundant interdisciplinary evidence that learners do not self-regulate by using these processes during learning and that they also do not adaptively modify their behavior, thus engaging in what we call dysregulated behavior. Dysregulated learning is a new term that is used to describe a class of behaviors that learners use that lead to minimal learning.

Ideally, learning about complex topics such as human body systems with MetaTutor requires the use of various self-regulatory processes. Initially, a learner begins by understanding task demands and the dynamic components of the task at hand. For example, this may include understanding the task, setting relevant sub-goals, understanding the role of the pedagogical agents, developing an internal representation of the structure of the non-linear and multi-representations content, recall strategies about how to best to approach the task, etc. An ideal self-regulating learner is not necessarily someone who is aware or understands these issues beforehand, but he/she uses appropriate monitoring processes and learning strategies during learning to continually maintain a sense of progress throughout the learning task. For example, they will use effective learning strategies such as drawing, taking notes, and coordinating informational sources to comprehend the material and build an internal mental representation of the topic. During task performance, they will also decide when to generate new sub-goals, abandon previously set sub-goals, and determine when sub-goals have been met. Other strategies include circumventing working memory (WM) limitations by off-loading difficult task elements and make best use of resources he has at hand at the time of performing the task. Afterwards, the ideal self-regulating learner engages in planning or goal-setting. Goal setting takes place at the beginning of the learning task, and the learner might also turn back and modify or eliminate the sub-goals he/she had set at the beginning; hence, the process is a cyclical one. At this stage, he sets task-relevant, manageable, and specific goals and sub-goals and prioritizes them prior to learning. He avoids setting narrow or broad sub-goals, and ideally settles on well-specified goals. This stage of the learning task is very significant, and the learner can benefit from assistance or sub-goal suggestions made by agents in computer learning environments like MetaTutor to calibrate his goals toward the overall learning task. By receiving prompts from MetaTutor, the learner actively engages in goal-setting and thinks about what he intends to achieve in the allotted time (e.g., 2-hour learning session). By contrast, a self-regulating learner, or a learner who doesn't self-regulate properly, tends to set either broad, narrow, or irrelevant sub-goals for the learning task, and thereby begin planning to focus his efforts on parts and material which is either irrelevant or does not lead to comprehensive learning.

Subsequent to setting goals and sub-goals, the ideal self-regulating learner takes into account the domain an topic of the learning task and activates prior knowledge and relates it to what he is going to learn (which may involve reading text and inspecting diagrams). Prior to the learning task, this may involve activating related schemata and mental models in long-term memory (LTM), and during learning the material, this may involve actively connecting what is being read to relevant material in the working memory, and making it easier and more appropriate for storage and future retrieval. Several cognitive and metacognitive processes are involved such as feeling of knowing (FOK) which indicates to the learner that he/she has or has not seen or be familiar with the content or domain, judgments of learning (JOL) are based on one's assessment of his/her emerging understanding, and content evaluation (CE) is a judgment to determine whether the hypermedia content is relevant (or irrelevant) to the current goal. These metacognitive judgments lead to the use of control processes that are behaviorally manifested as learning strategies. For example, a negative judgment of learning (JOL-) (e.g., not understanding the role of the pacemaker) may lead a learner to engage in goal-directed search for a specific page and/or medical illustration of the structure and location of the pacemaker. However, studies on the accuracy of metacognitive judgments like JOLs and FOKs have indicated that students are notoriously inaccurate when making these judgments (Nelson, 1996). Learners are often under- or over-confident in their judgments, but when they received prompts for making judgments and feedback on their performance by the agent in MetaTutor, they were less over- or under-confident, i.e. they become more metacognitively calibrated. Moreover, a higher Gamma correlation was found between the metacognitive judgments and subsequent performance of learners when they received prompts and feedback from the agent in MetaTutor in comparison to learners who did not receive prompts and feedback (Behnagh, Khezri & Azevedo, 2011).

One of the other characteristics of a good learner who self-regulates successfully throughout the learning task is using effective strategies, like note-taking, making inferences, drawing, paraphrasing, and summarizing accurately and at appropriate times. This way he reduces extraneous cognitive load, keeps track of what he reads, reformulates what he has just learned by saying it in his own words or re-representing it to another form like a diagram or drawing or a summary. The role of a pedagogical agent is also significant here. In environments like MetaTutor, the agent prompts the learner to summarize, for instance, or elaborate on the material just read. On the other hand, using ineffective strategies does not lead to deep understanding of the material. However, what are called 'ineffective' strategies can also be used adaptively given some circumstances, and can be useful for the learning of the material. In using learning strategies, poorly self-regulating learners either use ineffective strategies, or do not use effective strategies, or if they do, they do so for a very short period of time, and these lead to poor understanding and shallow processing of the material.

An ideal learner self-regulating learner efficiently keeps track of time on task, and does not spend disproportionate and unreasonable amounts of time on different sections of the task, sub-goals, or strategies. Moreover, intelligent learning environments like MetaTutor prompt learners when they spend an unreasonable time on one topic, sub-goal or page, thereby increasing the their metacognitive awareness and helping them (re-)direct their attention to more relevant material, and manage time more efficiently. A poor self-regulating learner, on the other hand, does not keep track of time, and spends a long time on irrelevant pages, or just visiting many pages, and seems not to stay on any relevant page long enough to acquire a deep understanding of the material.

During the process of learning, a good self-regulator takes steps back to check if he is progressing well toward the sub-goals set at the outset or not, and if he understands what has just been read is not sufficient or relevant, he takes measures to compensate for it and actively engage in strategies to learn more, and learn more efficiently. Also during the learning task, the learner asks questions about what has just been read, and checks if can answer those questions having read the material, and if not, he refers back to the text or his notes to overcome any lack of understanding. These self-checks include self-questioning, summarizing, making inferences, and engaging in knowledge elaboration. It should be noted that these are considered high-level self-regulatory processes that are seldom used by learners. MetaTutor attempts to prompt and foster the use of these processes during learning by posing questions relevant to each section in the form of short quizzes from time to time during learning, to help him recognize if he has understood the material or not, and if he sees that he cannot respond to those questions, he can actively engage in other strategies, like re-reading or asking the pedagogical agent for help. Poor self-regulating learners do not ask themselves if they understood or not, and keep reading, this way they lose the chance to refer back to the text or diagrams or to use efficient strategies to improve their understanding.

During learning, an ideal self-regulating learner develops an accurate and sophisticated internal mental representation of the content (e.g., sophisticated mental model of the circulatory system; Azevedo *et al.*, 2008; Chi *et al.*, 2001), and keeps comparing what he has just read to that model, and actively adds or modifies the representation as he progresses through the task. The development of an accurate and sophisticated mental model is the ultimate goal. However, under normal circumstances (e.g., in the absence of adaptive scaffolding) most learners do not develop sophisticated mental models. This is most often attributed to their lack of use of key SRL cognitive and metacognitive processes (see Azevedo *et al.*, 2011). In contrast, there is data that supports the notion the adaptive scaffolding on SRL and content does improve the quality of learners' mental models (e.g., Greene & Azevedo, 2009). As such, we and others have addressed this issue, by using artificial agents as external-regulating agents designed to detect, rack, model, and foster learners' SRL and content understanding (e.g., Azevedo *et al*., 2010b; Biswas *et al.*, 2005, 2010; Graesser *et al.,* 2008; McQuiggan & Lester 2009; White *et al*., 2009). In MetaTutor, there are four different agents, each with specific roles that have been designed to detect which specific SRL processes is used, when it is used and under what circumstances, is it used appropriately used given the circumstances, and was it effective in fostering learning.

In sum, learners do not typically regulate key aspects of the learning. More specifically, they tend to engage in dysregulated learning. Our focus is on identifying the nature of dysregulated learning and then using advanced learning technologies such as intelligent, adaptive multi-agent systems like MetaTutor to detect, track, model, and foster students' self-regulated learning. There are many scientific, technological, and computational challenges that lie ahead.

However, recent interdisciplinary research is leading the way solving some of these challenges as we design advanced learning technologies to support students' life-long learning (e.g., see Biswas *et al.*, 2010).

Conclusion and Future Challenges

Intelligent learning environments, like MetaTutor, can significantly transform how we support students' self-regulated learning. The focus has been almost exclusively on the detection, tracking, modeling, and fostering cognitive and metacognitive processes. There are however other areas that have largely ignored by researchers—e.g., the roles of motivation and affect in SRL. A comprehensive model of SRL must include cognitive, metacognitive, affective, and motivational processes. For example, one of the significant challenges raised in a recent review by Moos and Marroquin (2010) is the neglected area of motivation in computer-based learning environments. They emphasize the need for more to examine the role of motivational processes such as task value, self-efficacy, and interest as critical processes underlying students' self-regulated learning (e.g., Moos & Azevedo, 2009).

The role of affect has to be taken into consideration when examining the role of self-regulated learning with advanced learning technologies. Recent work has focused on the role of affect on students' learning in science and math and been instrumental in detecting and classifying various emotions during learning (e.g., Azevedo & Chauncey, in press; Calvo & D'Mello, in press; McQuiggan, Robison, & Lester, 2010). Further work on affect should focus on understanding how affect may influence cognitive and metacognitive processes in and either (temporarily) impeded learning and foster learning with advanced learning technologies. Similarly, work on affect regulation is needed to determine how learners monitor and control their emotions during learning about complex and challenging topics and domains. These are a few of the critical issues that need to be investigated so that we can advance the field of SRL and build learning technologies that are truly capable of supporting students' cognitive, metacognitive, motivational and affective self-regulatory process. In sum, understanding how motivational and affective processes contribute to students' dysregulated learning with advanced learning technologies will provide a more comprehensive view of dysregulation during learning.

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